DEVELOPING A KNOWLEDGE-BASED EXPERT SYSTEM TO DETERMINE
CONTRACT DURATION FOR HIGHWAY CONSTRUCTION

By

WEI-TONG CHEN

Dedicated to my parents, my wife, and my family members.

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In today's highway construction industry, the focus of
the work has shifted from the building of new highway systems
to the resurfacing, rehabilitating and restoring (3Rs) of
those already in existence. As a result, the flow of traffic
must be maintained with the required lane and shoulder
restrictions throughout the construction of the project.

Appropriate contract durations allow the contractor
sufficient time to complete the work, while at the same time
minimizing the disruption to the flow of traffic and other
construction-related inconveniences that may be experienced by
the traveling public. An appropriate contract duration should
be agreeable to both the state highway agencies (SHAs) and the
contractor, thereby reducing the incidence and severity of
potential contractual disputes. Most importantly, however,
proper contract durations must be established so that the

financial interests of both the SHAs and the general public remain paramount.

This research was devoted to developing EXCONDD, a knowledge-based expert system (KBES) for contract duration determination for highway construction. Various contract duration influence factors and the overview of KBES were addressed in detail.

Three commercial software packages are used in EXCONDD. Among these software, EXSYS Professional plays the most important role because it controls the execution of the entire system. Lotus 123 is utilized to establish various templates. Suretrak Project Scheduler takes charge of project scheduling.

EXCONDD includes three modules: the parametric estimating time (PTE) module, the production rates module, and the "A+B" module. The production rates module can only be utilized to estimate contract duration for highway widening and resurfacing projects, while the other modules are applicable to any type of project with no restriction. Knowledge and expertise of EXCONDD was extracted mainly from SHAs guidelines and experienced schedulers in the field of highway construction. By integrating these three modules, contract duration of highway project can be easily determined.

CHAPTER 1
INTRODUCTION AND PROBLEM STATEMENT

An Overview of the Highway System in the USA

Highway transportation is integrated with every phase of life in the United States. Highways are essential to individuals for work- and school-related trips, for delivery of services and goods, and for the myriad of social and recreational activities people in a complex modern society enjoy. Cars, vans, trucks, and other vehicles cover the nation's highways, with drivers who have come to anticipate speedy, comfortable, and efficient trips at times they choose and to destinations throughout the country.

Industry and businesses also depend on the interconnected highways that are vital to the nation's economy, providing a foundation critical to the industrial and technological complex of the United States. Trucks carrying goods and produce can reach remote settlements by travel on the network of roads throughout the enormous land mass of the continental United States. Maintenance of the existing roads is essential to the well-being of the country. Construction of new highways is ongoing as the mobile population establishes new homes and businesses in formerly rural areas.

The importance of the highways is evident in statistics. Thirty-two percent of the nation's total revenue ton-miles of freight and 90 percent of personal transportation are served by highways (Larson, 1992). The Interstate system, originally thought of as a means of assuring military transportation in event of attack, is now the transportation means of choice for citizens and businesses alike. Currently, the Interstate system carries 22.3% of total travel as shown in Figure 1-1. This dependence of the United States upon highway travel in terms of the nation's history is a relatively recent development.
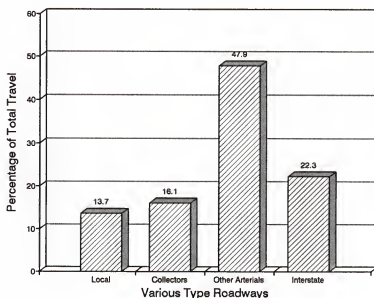
Source: Larson, 1992

Figure 1-1 Distribution of Roadway Travel

From the earliest periods of United States history, given the vast distances confronting settlers, transportation has been a major goal. Technological changes brought new opportunities such as the steamboat and the railroad. Prior to the Second World War, railways dominated much of the nation's freight and passenger movement. Gasoline shortages during the war slowed the growth of motor transportation. After the war, once fuel was available and good roads were constructed, motor transportation grew at increasing rates. The massive building of highways in the 1960s and 1970s established highway transportation as the dominant model of transport in the United States. Increasingly, the highways were designed to provide convenience, speed, and comfort to the traveling public.

In the 1980s and the 1990s, however, the total mileage of roads has increased by only 4%, while the number of vehicles using the roads has increased by 78% (Larson, 1992). Traffic volume is destructive; the highways show wear. The huge growth in the number of vehicles using the Interstate system has lowered the overall Interstate Present Serviceability Rating (PRS), which reflects pavement conditions, with a scale from 0 to 5. Figure 1-2 and Figure 1-3 indicate that the serviceability of the Interstates are in crucial shape.

At the same time, the steadily increasing costs involved in building new major roads have made construction prohibitive in most instances. Rehabilitating the existing highway has

PSR: Present Serviceability Rating

Figure 1-2   Urban Interstate Highway Pavement Condition

PSR: Present Serviceability Rating

Figure 1-3 Rural Interstate Highway Pavement Condition

become the only feasible way to maintain the roads. The major areas of highway rehabilitation include pavement and shoulder, right-of-way, grading and earthwork, drainage and erosion control and other miscellaneous items. It should be noted that a considerable expenditure will be required for the rehabilitation job. Table 1-1 shows the Federal Highway Administration's projected expenditure needs for Interstate highway rehabilitation from 1985 to 2000. The projected needs base on the annual rates of travel growth for 2.15% and 2.85%.

Table 1-1 Expenditure Needs for Rehabilitating Interstate Highways from 1985-2000 (In Millions of 1985 Dollars)

Annual Rates of Travel Growth	Urban		Rural	
	2.85%	2.15%	2.85%	2.15%
Reconstruction to Freeway Standards	338	284	90	75
Reconstruction with Added Lanes	5,802	4,002	1,255	794
Reconstruction with Wider Lanes	74	46	0	1
Reconstruction with Pavement	3,464	3,288	58	57
Major Widening	23,357	18,053	11,657	7,566
Minor Widening	120	123	11	
Resurfacing with Shoulder Improvement	560	586	415	420
Resurfacing	18,824	18,907	16,056	16,093
TOTAL	52,547	45,288	30,769	26,504

It is apparent that today's highway construction industry has shifted from building new highways to the 3Rs: Resurface, Rehabilitate, and Restore existing highway systems. Due to the trend of the 3Rs, traffic must be maintained with lane and shoulder restrictions while the reconstruction takes place. It is, therefore, desirable to provide the shortest practical construction duration that will minimize disruption of traffic but still allow the contractor a reasonable amount of time to complete the work. Consequently, the procedure to establish appropriate durations for highway construction projects is more critical today than ever before.

Definition of the Contract Duration

Contract duration (CD) can be defined as "the maximum time allowed to the contractor for completion of all work contained in contract documents" (Federal Highway Administration, 1991). Contract duration is normally established prior to bidding by the project owners. It is based on the urgency of the project, normal execution techniques, reasonable conditions and average durations that most contractors would apply or face on the project. However, the level of detail used to estimate contract duration by the owners need not and should not be as fine as the schedules prepared by the contractors.

Generally, penalties are applied to contractors for their delay in completing a project. On the other hand, bonuses

are, sometimes, provided to reward contractors for their early completion of the project. If the delay of the project is caused by the owners, extra time should be given.

Contracts specifying more duration than is actually needed for a project may discourage good construction management techniques, introduce higher agency costs, permit low-productivity contractors and encourage them to bid for more work than they can handle. As a result, the contractors may offer lower bid prices.

Contracts providing less duration than is necessary for completion of a project may initiate higher bid prices and eliminate qualified contractors. However, they can encourage good management practices, high productivity, and lower agency costs. In addition, public safety and efficiency of the transportation system will be improved by allowing the facilities to open earlier. Figure 1-4 summarizes the role of appropriate contract duration.

A reasonable contract duration helps to eliminate the possibility of disputes between the contractors and the owners. More importantly, it reduces the related time of inconvenience to the road or facility users. In turn, this provides savings of various costs to the traveling public and the SHAs. For this reason, many SHAs devote considerable efforts and time to establish reasonable contract durations for highway construction projects.

```
┌─────────────────────────────────────────┐
│ * Discourages Good Constr. Mgmt.         │
│ * Encourages Contractors to Bid More Work│
│ * Increases Agency Costs                 │
│ * Permits Low-Productivity Contractors   │
│ * Lowers Bid Prices                      │
└─────────────────────────────────────────┘
              ▲
        ┌──────────────┐
        │ More Than Needed │
        │ CONTRACT     │
        │ DURATION     │
        │ Less Than Needed │
        └──────────────┘
              │
              ▼
┌─────────────────────────────────────────┐
│ * Encourages Good Contr. Mgmt.           │
│ * Increases Productivity                 │
│ * Lowers Agency Costs                    │
│ * Increases Public Safety                │
│ * Higher Bid Prices                      │
└─────────────────────────────────────────┘
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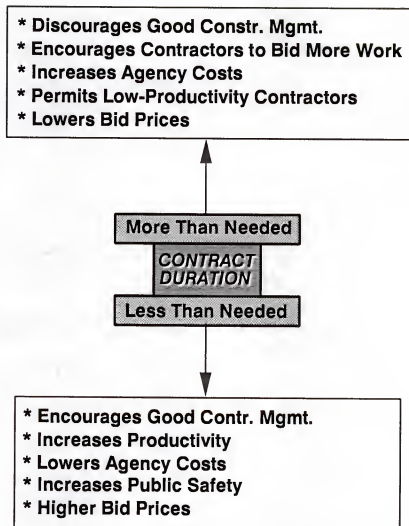
Figure 1-4   The Role of Contract Duration in the
             Construction Process

Measuring Contract Duration

Contract duration is measured by different time units such as working day, calendar day, completion date or a combination of these. The use of these time units is mainly dependent upon the size, urgency and length of the project as well as other considerations. The definitions of various time units are described as follows.

Working days: The days that the contractor can work (excluding weekends, holidays and nonworking days).

Calendar days: The days between the project start date and the completion date without excluding any day.

Completion date: A specific date that the project must be finished prior to.

Each time unit has its own strength and weakness. There is no clear-cut way to determine which time unit is the most preferred one. A brief comparison of these time units is presented in Table 1-2.

Table 1-2 Comparison of Various Time Units

Time Units and Items	Definition	Total Project Time	Project Completion Date
Working Day	Very Difficult to Define	Very Clear	Not Clear
Calendar Day	Easy to Define	Very Clear	Clear
Completion Date	Very Easy to Define	Not Clear	Very Clear

In order to review the practice of time units, Hinze and Coleman (1991) conducted a nationwide survey to investigate the use of time units within 50 SHAs. This survey concluded that most agencies utilize a combination of more than one time unit to measure contract duration as shown in Figure 1-5.
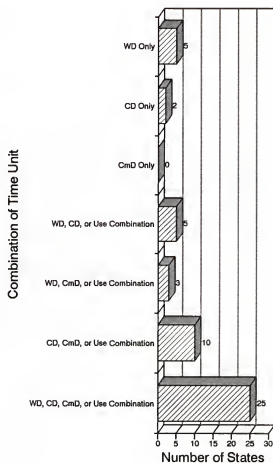

```
WD: Working day
CD: Calendar day
CmD: Complete Date
```

Source: Hinze and Coleman, 1991

Figure 1-5   Current Practices of Time Units in the USA

Problem Statement

Before the contract is awarded, it is practically impossible to obtain an accurate contract duration for the project. However, project owners have to do their best to set a project duration for upcoming bids. Setting appropriate contract durations for highway construction projects is complicated and involves a number of complex issues. Several important aspects of this procedure are 1) knowledge of the highway construction process, 2) measurement of the impact of contract duration influence factors, and 3) utilization of scheduling techniques such as Barchart and CPM.

Assessing the impact of contract duration influence factors is difficult because of their qualitative characteristics. Although various written procedures and guidelines have been developed for contract duration estimating, the measurement of such impact is still heavily dependent upon the engineer's experience, judgement, and historical project data. As a result, the collection of information and expertise has become an important part of contract duration estimation.

In general, project owners or SHAs take responsibility for setting reasonable contract durations. Their knowledge and experience of highway construction plays a crucial role in successfully determining appropriate contract durations. However, not all the owners and SHAs have sufficient knowledge and experience to get the job done well. This is particularly

true of the project owners who usually do not have sufficient information about the contractors such as their available resources and crew sizes. The situations deteriorate if several project contract durations have to be determined in a short period of time.

Considering the complications involved with the estimation of contract durations, it becomes an issue of top priority to develop a systematic approach to assist project owners and inexperienced scheduling engineers to establish appropriate contract durations for highway construction projects.

Research Objectives

The primary objective of this research effort is to develop a knowledge-based expert system (KBES) approach to assist project owners and inexperienced engineers in estimating contract duration for highway construction. A schematic flow chart, shown in Figure 1-6, has been developed to show the key components of this research. The primary research objective is further divided into several subobjectives listed as follows:

1) To investigate various procedures currently followed by the SHAs for contract duration determination based on publishing literature, a nationwide survey, and interviews with scheduling experts in the field of highway construction.
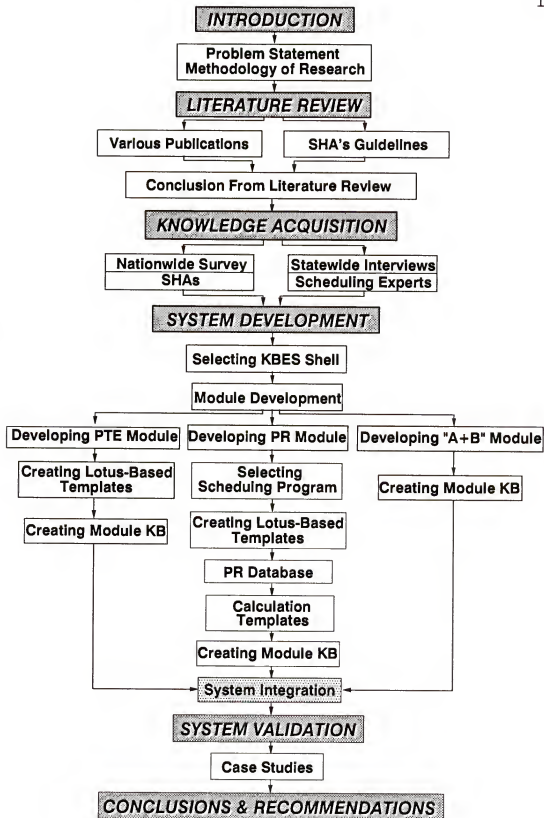
Figure 1-6 Flowchart of the Research Development

2) To investigate various influence factors and evaluate their impact on contract duration determination for highway construction.

3) To develop a KBES to estimate contract duration by integrating the EXSYS Professional, Lotus 123, and Suretrak Project Scheduler.

4) To validate the prototype system by testing real-world highway construction projects.

5) To summarize the final outcomes and discuss the conclusions of the research and make recommendations for future research.

It is apparent that each project may be subjected to a unique set of influence factors. The impact of individual influence factors as well as their combined impact varies with projects. Any system for predicting contract duration will thus have to be custom tailored to a specific project. Thus, research emphasis is directed towards developing a general procedure rather than a single specific one. This approach permits a more general application of the research results.

<u>Research Methodology</u>

The research methodology employed in this dissertation consisted of several major phases including a literature survey, knowledge extracting, system development, and system validation. These phases are briefly addressed next.

Literature Survey

To obtain a more comprehensive understanding of the problem, the first phase of this study was devoted to gathering information generated by previous researchers. The literature survey concentrated on three areas:

1) Procedures that are used to estimate contract duration

2) KBES application in the field of construction engineering

3) Scheduling methods that are used to establish contract duration

Knowledge Extracting and Analyzing

The reliability of any KBES stems from the integration and accuracy of its knowledge base. In general, while developing a KBES, the majority of the time is consumed in collecting and organizing its knowledge base. To establish the knowledge base, several activities were carried out. These activities were:

1) Examining the highway construction process

2) Identifying contract duration determination influence factors

3) Conducting a nationwide survey

4) Conducting interviews

5) Analyzing and organizing the knowledge obtained.

System Development

The knowledge base of the system was established in accordance with the information gathered from the previous phases. Following that, various data bases and templates were created. Involved software was integrated into the system. Activities completed in this phase were

1) Establishing the knowledge base of the developing system
2) Selecting an expert system shell
3) Selecting a scheduling software
4) Developing various secondary files
5) Integrating various software which were used.

System Validation

In this phase several real-world projects, including on-going and finished projects, were utilized to validate the developing system. The results of validation led to further refinement of the system. Based on the same testing results, recommendations for future research in the subject area were made.

Research Scope

Three different modules were included in the developing system. One module was limited to the contract duration estimation of asphaltic highway widening and resurfacing projects excluding bridge structures. The other two modules

can be applied to any type of highway project with no restriction.

Organization of the Dissertation

This dissertation is organized as follows: Chapter 1 introduces the problem and defines the research objectives and methodology. Chapter 2 is a review of the literature of related research works. Chapter 3 examines highway construction contract duration influence factors and their impact on contract duration determination. Chapter 4 provides an overview of the knowledge-based expert system. Chapter 5 depicts the approach and procedures of knowledge acquisition utilized in this research. Chapter 6 addresses the development and integration of the prototype system. Chapter 7 validates the prototype system using six real-world projects. Chapter 8 summarizes the conclusions of this research and provides recommendations for future study.

CHAPTER 2
REVIEW OF THE LITERATURE

Introduction

It is apparent that a reasonable contract duration is the first phase of generating a successful project for both owners and contractors. The project owners arrange their budget and payment according to the project contract duration. Contractors manage their resources and perform construction work based on the contract duration. Ultimately, the contract duration governs most aspects of the project.

In this chapter, various contract duration determination methods including conventional and innovative approaches are examined. An overview of the knowledge-based expert system, as well as its application in the construction industry, is also addressed. In addition, conclusions based on the literature review and recommendations for further research are provided.

Current Practices of Contract Duration Determination

Substantial time and effort have been spent in trying to determine the contract duration for highway construction projects. Although various written procedures have been

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developed, they are not significantly different in their methods and reasoning. In general, the major intent of written procedures is to provide a guide for contract duration determination that will 1) provide a tool to establish a realistic contract duration; 2) maintain a consistent contract duration for similar projects; and 3) not be very cumbersome or time consuming. Figure 2-1 presents the procedure for setting contract duration for highway construction projects.

In order to investigate current practices for contract duration determination, a questionnaire as shown in Appendix A was conducted and distributed to all the SHAs in the USA and Canada. The questionnaire was based on a literature search of related subjects and various procedures utilized by different states. This questionnaire mainly consisted of two major categories of questions: 1) the methods of determining contract duration and 2) the influence factors of determining contract duration for highway construction.

Sixty-four surveys were sent out and a 67% return rate (43/64) was achieved. Of the 43 responses, 38 were from the USA and five were from Canada. Therefore, it should be noted that the survey responses more strongly reflect trends in American highway construction practices rather than Canadian.

The survey responses were analyzed and organized as shown in Table 2-1. Detailed discussion of related survey subjects such as contract duration determination methods, scheduling techniques, and various time units is presented next.
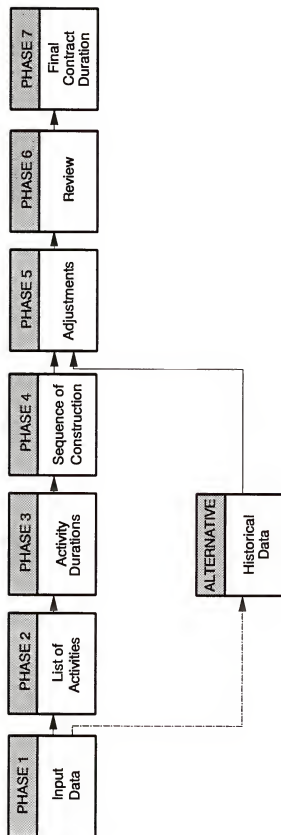
Figure 2-1 Basic Phases in the Contract Duration Determination Process

TABLE 2-1 Current Practices of Contract Duration Determination

STATES And PROVIDENCES	CD Determination Apporach										
	Convential Approach								Innovative Approach		
	Production Rates Method					Constr. Season Limited	Parametic Estimating Method	Non Formal Method Used	A+B Method	Lane Rental	I/D
	Use Production Rates	CPM Method	Bar Chart	Simplified Method	Un-Specify						
ALABAMA								X			
ALASKA								X			
ARIZONA			X				X				D
ARKANSAS	X		X						X(e)	X(e)	X
CALIFORNIA	X	X					X		X(c)		
COLORADO	X	X(l)	X(m)						X	X	D
DELAWARE	X*				X		X#				X
DIST. OF COLUMBIA	X*				X$		X#		X(s)@		
FLORIDA	X	X	X								X
GEORGIA	X	X	X						X	X	X
HAWAII	X		X								X
IDAHO	X		X							X	
ILLINOIS	X		X								
INDIANA	X		X							X	X
IOWA	X	X									X
KANSAS	X		X								X
KENTUCKY	X		X						X		X
LOUISIANA	X			X							X
MAINE	X		X							X(l)	X
MARYLAND	X		X						X	X	X
MICHIGAN	X	X									X
MISSISSIPPI	X		X						X		
MISSOURI	X		X						X(l)		X
MONTANA	X			X							
NEBRASKA	X			X							X
NEVADA	X	X	X(m)							X(s)	
NEW HAMPSHIRE	X				X				X		X
NEW JERSEY	X		X						X		X
NORTH CAROLINA	X		X						X(l)	X(l)	X
OHIO	X(c)	X					X(m)		X	X	X
OREGON	X	X									
PENNSYLVANIA	X		X						X(l)		X
RHODE ISLAND	X	X					X				X
SOUTH CAROLINA	X		X								X
TEXAS								X			X
WASHINGTON	X	X	X								X
WISCONSIN	X		X								X
WYOMING	X	X									X
ALBERTA	X	X	X								D
MANITOBA	X										D
NORTH BRUNSWICK	X				X						D
NEW SCOTIA						X					D
SASKATCHEWAN	X			X							D

NOTES: X(m)- For Most Projects, X(s)- Special Case Only, X(c)- Critical Project Only, X(e)- Experimental Stage Only, X(l)- Limited Use,
I- Incentive, D- Disincentive

Methods Used by SHAs for Contract Duration Determination

Several methods with different complexity have been used for contract duration determination. These methods can be classified into two main categories: the conventional approach and the innovative approach. The conventional approach was utilized extensively during the past and has gained satisfactory results. However, the emphasis on the value of time has grown significantly in today's highway construction compared to the past. As a result, the innovative approach was created to reduce project time to respond to the great emphasis on time value.

According to Figure 2-2, about half of the respondents use only one method to determine contract duration. And slightly less than one third of all SHAs use two different methods. Only one SHA applies four different methods to estimate contract duration. Moreover, some SHAs still do not have formal methods for contract duration determination.
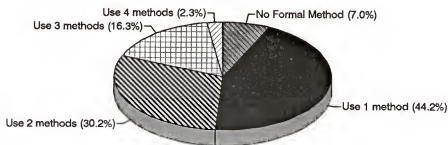
Figure 2-2   Distribution of Methods Used by SHAs for
Contract Duration Determination

Based on Figure 2-3, the production rate method clearly dominates all other methods. It is also apparent that innovative approaches are applied only when the production rates method is used. No SHA uses the combination of the production rates method, parametric time estimating (PTE) method and lane rental (LR) method.
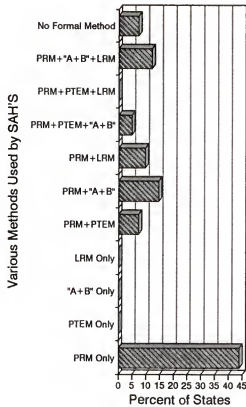

```
"A+B": "A+B" Method
  LRM: Lane Rental Method
  PRM: Production Rates Method
 PTEM: Parametric Time Estimating Method
```

Figure 2-3   Various Contract Duration Determination
Methods Utilized by SHAs

Compared to the similar survey conducted by Ackerman (1981), the use of the innovative approach has slightly increased. Although still at the experimental stage, the innovative approach has enormous potential for becoming the most popular method of determining contract duration in the near future. Use of these two approaches is discussed next.

The Use of the Conventional Approach

The conventional approach mainly includes two methods: the production rates method and the parametric time estimating (PTE) method. The use of the production rates method involves not only work production rates but also various scheduling techniques. The parametric time estimating method, on the other hand, is very easy to use. However, this method is not able to generate accurate results because of its roughness.

The production rates method

The production rate is defined as the amount or quantity produced over a specified time period. In general, the use of the production rates method involves three components: a reliable database of production rates, an experienced scheduling engineer, and an appropriate scheduling method. Table 2-2 and Figure 2-4 display different ways of expressing production rates.

The accuracy of the production rates method is heavily dependent upon the actual production rates achieved under similar conditions on previous works. To obtain a higher

Table 2-2   Partial List of Production Rates Used by the
            Louisiana SHA

SECTION	ITEM	PRODUCTION RATES
201	Clearing and Grubbing	1.5 Acres/Day
202	Removal of P. C. C. Pavement	2 Spans/Day
202	Removal of Concrete Box Culverts	500 SY/Day
203	Excavation or Embankment (Figure highest qty only)	3,000 CY/Day (Rural) 1,000 CY/Day (Urban)
203	Borrow or Truck Hauled Embankment	3,000 CY/Day (Truck Hauled)
203	Mucking Ditches (consider section)	1,000 Ft/0.5 Mile/Day
203	Mucking (very large quantity)	3,500 CY/Day
203	Shaping Roadbed	1 Mile/Day
203	Shaping Roadbed, Ditches & Slopes	0.5 Mile/Day
203	Shell Embankment	2,500 CY/Day
301	Base Course (Class I)	1,000 CY/Day
301	Base Course (Non stabilized)	1,500 CY/Day
302	Scarifying and Compacting Roadbed	1 Mile/Day 2 Lane Miles/Day
303	In-Place Cement Stabilized Base Course	6,000 SY/Day (Roadway)
304	Lime Treatment (24 Ft. Width) (20 Ft. Width)	6,000 SY/Day 5,000 SY/Day
305	Subgrade Treatment (Working Table)	8,000 SY/Day
401	Aggregate Surface Course	300 CY/Day
501	Asphaltic Concrete (less than 20 tons or broken construction)	500-1,000 Tons/Day
501	Asphaltic Concrete (typical overlay or construction)	1,000 Tons/Day

Source: Survey response by the Louisiana SHA
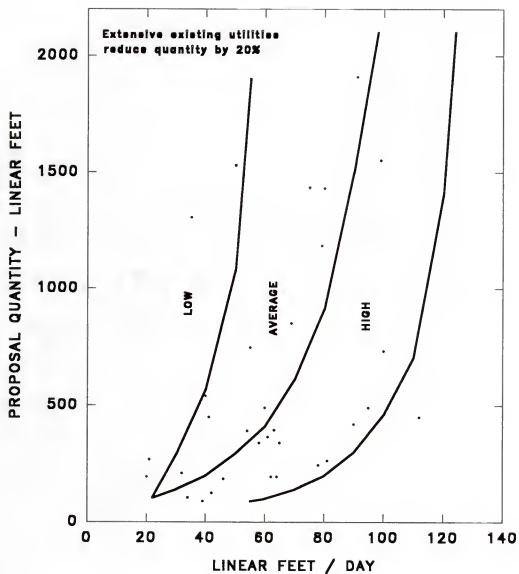
: Survey responses from the Maryland SHA

Figure 2-4   Partial List of Production Rates Used
by the Maryland SHA

level of accuracy, it is important to establish a reliable database of production rates based on 3 to 5 years' historical information. In addition, production rates should be adjusted according to the requirements of individual projects.

Selecting appropriate production rates for work items involves numerous considerations such as project location, project size, and weather conditions. Since the impact of these factors is difficult to evaluate, the scheduler's judgement and experience play a critical role.

The procedure for estimating contract duration using the production rates method can be broken down as follows:

1) Identify work items for the project
2) Develop the construction logic and sequence
3) Estimate activities duration (in working days)
4) Adjust activities duration considering the impact of influence factors
5) Calculate project duration using scheduling method or simply cumulating the durations of control items.
6) Convert working days into required contract time unit such as calendar days or completion date.

Several scheduling techniques such as the barchart, critical path method (CPM), line of balance (LOB), and time scale diagram (TSD) have been used by SHAs for contract duration estimation (Hancher and Rowings, 1981; Herbsman, 1987; Rowings and Rahbar, 1991). However, the CPM and barchart are the most important ones as shown in Figure 2-5.
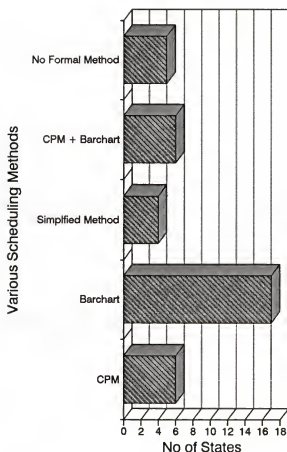
Figure 2-5   Various Scheduling Methods Used by SHAs
for Determining Contract Duration

Figure 2-5 indicates that the barchart, the CPM, and
their combination play the dominant role among the scheduling
techniques.   In addition, 13.2% of the SHAs still do not
employ any scheduling technique to estimate contract duration
when they use the production rates method.   The following
section addresses various scheduling techniques used in the
production rates method.

Barchart. Used as a scheduling tool since the early twentieth century, the barchart is one of the most popular techniques for contract duration estimation. In a barchart, project work items are listed in vertical order, while their corresponding durations are plotted as horizontal bars on the time graph. Special conditions such as overlapping and waiting time can also be considered. The project duration is indicated by the far end of the most far activity in the chart. An example of a barchart generated by the New Jersey SHA is shown in Figure 2-6.

The major advantages of the barchart have been recognized by researchers (Al Sarraj, 1990; Reda, 1990). Among the most important are its simplicity and the graphic visibility of the whole project. Easy to read and interpret, the barchart has been widely accepted as an effective planning and scheduling tool for certain types of projects such as highway and pipeline construction.

The main disadvantage of the barchart is its failure to display interdependencies between the activities. Thus, the critical activities that control the project duration cannot be identified and shown in a barchart. In addition, there is no indication of the overall impact on the schedule if an activity is delayed (Rowings and Rahbar, 1991). Although a barchart is very efficient in demonstrating a proposed schedule for construction projects, it is ineffective in controlling the schedule of such projects (Herbsman, 1987).
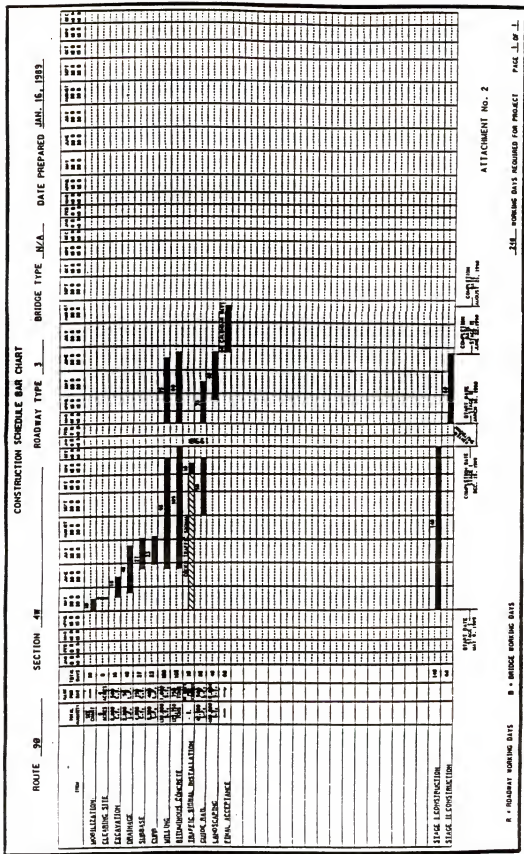
Source: Survey response by the New Jersey SHA

Figure 2-6 Example of Barchart Used for Contract Duration Determination

Critical path method. Developed in the late 1950s and early 1960s, the critical path method (CPM) occurs either as an arrow diagram method (ADM) or a precedence diagram method (PDM). In both versions, the interrelationships of the activities are illustrated by the arrows which connect the nodes. The primary difference between the two methods is that the ADM defines the activity by an arrow between two numbered notes, while the PDM defines the activity by a node between arrows. In general, certain information such as activity description, activity duration, and activity dependency must be prepared to generate a CPM schedule.

In general, CPM is utilized on those projects that are logically deterministic and consist of activities with assumed deterministic parameters. Activities logical sequence and critical activity can be clearly identified in a CPM diagram. An example of a CPM generated by Michigan SHA is presented at Figure 2-7.

Although CPM is a well-established and easily understood scheduling technique, several major drawbacks of the CPM have been identified. First, CPM is not able to guarantee maintaining of the continuity of work because it schedules the start of each activity as soon as all its preceding activities are finished. Second, CPM leads to a complex and cluttered network which is difficult to visualize when it is utilized in repetitive activity projects (Rowings and Rahbar, 1991). Third, CPM reduces project duration by shortening the duration

Source: Survey response by the Michigan SHA

Figure 2-7   CPM on the Arrow Diagram Used by the Michigan SHAs

of the critical activities which is done by increasing the
production rates of these activities. This may result in
different production rates for similar activities at different
stages, where some of these activities may be critical (Reda,
1990). The use of the ADM in construction industry has
decreased dramatically because it is unable to demonstrate
different activity dependencies such as SS (start to start),
SF (start to finish) and FF (finish to finish). Unlike the
ADM, the PDM has became the major scheduling technique
utilized in the construction industry because of its ability
to define various activity dependencies.

Linear scheduling method. The utilization of the
linear scheduling method (LSM) results from the recognition of
the difficult use of network model when scheduling repetitive
projects. The origin of the LSM is not clear and there may
actually have been multiple origins. Even the name attached
to the method has variations and it has appeared in the
literature as vertical production method (VPM) (O'Brien,
1975), flow line method (FLM) (Stradal and Cacha, 1982), line
of balance (LOB) (Arditi and Albulak, 1986), and repetitive
production method (RPM) (Reda, 1990). LOB is perhaps the most
frequently used name.

As shown in Figure 2-8, LOB was first used in industrial
manufacturing and production control with the object of
evaluating the flow rate of finished products in a production
line (Al Sarraj, 1990). No significant distinction exists
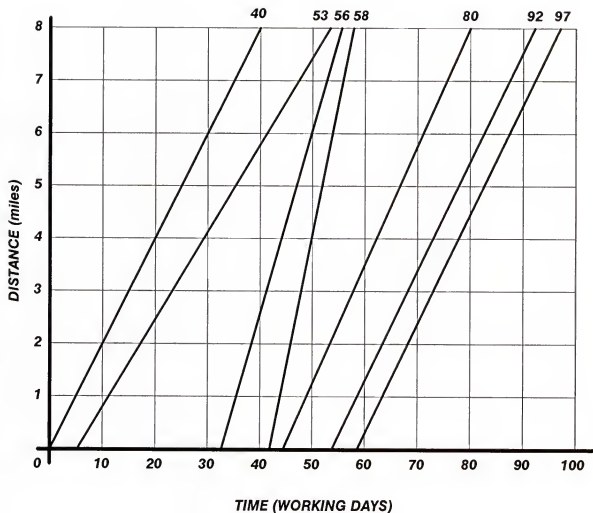
Source: California SHA, 1991

Figure 2-8   Example of Line of Balance Used to
Determine Contract Duration

between LOB and LSM. However, they are slightly different in terms of emphasis. LOB places more emphasis on the balance of the progress diagram while LSM emphasizes the purposes of planning.

LSM is extremely visual because it clearly shows the speed of activities through the segments. Therefore, most construction operating personnel can relate to this technique easily. It can also be utilized as a planning device for comparing different scheduling alternatives of various working rates and different section divisions. Furthermore, changes and delays can be incorporated easily and the effect of these changes on the time is minimal.

Although LSM has potential as a management and operational tool in linear projects, its disadvantages should be noted. One disadvantage of this technique is that there are severe applied limitations to its use in nonrepetitive projects. This method is rarely used in the United States although it is vary popular in the Middle East where it is used in linear projects (Herbsman, 1987).

Time scale diagram. In a time scale diagram (TSD) shown in Figure 2-9, each activity is presented by a bar or an arrow with a scale while showing relationships. The TSD's value lies in analysis of scheduling variables such as activity, section, duration and influencing factors such as repetitive work, use of section space, and balancing of activity speeds (Stradal and Cacha, 1982). The TSD can satisfy those people
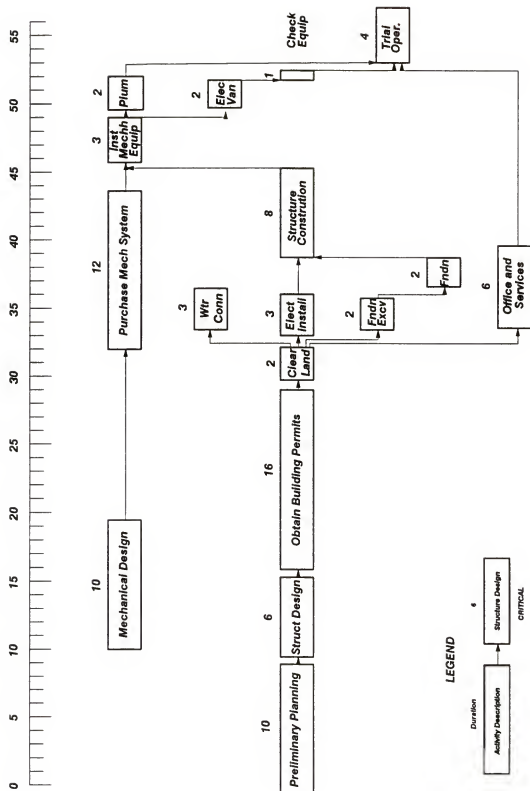
Figure 2-9 Example of Time Scale Diagram Used to Determine Contract Duration

who favor the bar chart because of the TSD has characteristics similar to the barchart.

Simplified method. In addition to the scheduling techniques described above, a simplified method was also developed to determine contract duration. The major difference between the simplified method and other scheduling methods is that the simplified method only considers the durations of the major work items, while the other scheduling methods concern the durations of all work items in most cases.

To use the simplified method, the scheduling engineer calculates the durations of the major work items for the project by utilizing the production rates method. Project contract duration is then computed by adding up these major work durations. The project contract duration may be modified based on the scheduler's experience and judgement. Figure 2-10 displays a contract duration form which was developed for utilizing the simplified method.

When using the simplified method, a working day time unit is utilized to measure contract duration. However, contract duration can be converted from working days into calendar days by multiplying a conversion factor which is the ratio of the weekly calendar days to working days. For example, Florida SHA uses a conversion factor of 1.46 (7/5) based on five working days per week.

Although the simplified method is able to determine contract duration in a very short period of time, it is not a

<table>
<tr><td>IOWA
DEPARTMENT
OF
TRANSPORTATION</td><td>LETTING   2-21-92
PROJECT DATA SHEET   34
DISTRICT   2
COUNTY   HOWARD
PROJ. NO.   BRF-272-1(6)- - 38-45
WORK TYPE   BRIDGE (new)</td></tr>
</table>

ESTIMATE OF TIME REQUIRED

ITEM	UNIT	QUANTITY	RATE PER DAY	DAYS	DAYS NOT AFFECTING TIME LIMIT	TOTAL DAYS REQUIRED
Excavation Class	Cu. Yds.					
P.C.C. Pavement	Sq. Yds.					
A.C.C. Binder and Surface Course	Tons					
Gravel or Crushed Stone Shoulder	Tons					
Seeding	Acres					
Guardrail	Lin. Ft.					
Remove Existing Structure	L.S.			10	7	3
147'x32' PPCB 3 span over creek	Sq.Ft.	4704	Chart	34		34
Concrete Barrier Rail	1 in. Ft	328	50	7		7
Clean Up						1
Total Working Days Required						45

TWF 8-20-91

Prepared By: DRT   Date: 12-18-91

Comments: Road closed by ACC contractor.
No winter Free Time
Approx. Start 4-27-92
Use 55 working days since RCB project needs 55.

Source: Survey response by the Iowa SHA

Figure 2-10 Simplified Form Used by the Iowa SHA
to Determine Contract Duration

highly reliable method because it considers only major project work items. In addition, this method ignores the impact of the lead time between major work items. Therefore, the simplified method is recommended only for contract duration estimating of small or simple projects.

Parametric time estimating method

Parametric Time Estimating method (PTE) is based on the relations between time and various project parameters such as total cost, length, and lanes in accordance with statistical analysis of historical project data. The accuracy of this method is heavily dependent upon the volume of available historical data. Therefore, the more project data gathered, the higher the accuracy that can be achieved.

Among various project parameters, the project total cost is the most popular parameter utilized to estimate project contract duration. For example, the states of New Mexico and Delaware determine contract duration by using historical project total costs as shown in Figure 2-11. The Nebraska SHA also uses this method to determine contract duration for certain type of projects such as culverts and bridges.

One of the advantages of the PTE method is that it can be utilized at very early stages of design. By utilizing the PTE method, scheduling engineers are able to estimate contract duration based on budget configurations without detailed plans or bid documents. However, the method is only appropriate for small or simple projects because of its approximations. It
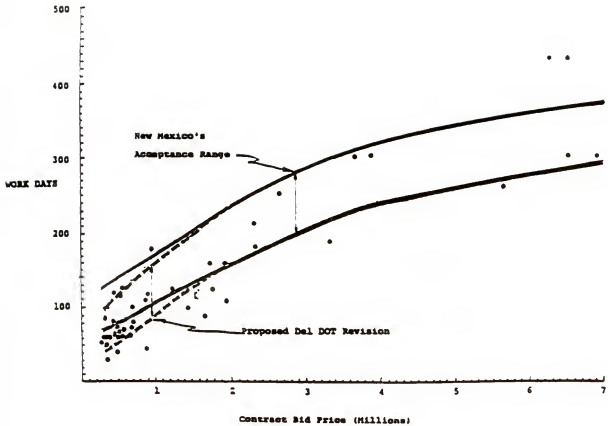
Source: Survey response by the Delaware SHA

Figure 2-11   The Use of the Parametric Time Estimating
              (PTE) Method (Cost vs Time) for Contract
              Duration Determination

can also be utilized to check the contract duration estimated using other methods.

The Use of the Innovative Approach

In highway construction, time is of the essence for critical projects which involve disruption of high traffic volumes or lengthy detours. Thus, early completion of the critical projects will benefit the traveling public. It is hoped that the innovative approach will reduce project duration and to ensure the timely completion of the project.

The innovative approach is not an entirely new idea but it was not substantially used much in the past. Although it is in the experimental stage, the innovative approach is projected to become the most promising method of determining project contract duration because of its ability of reducing construction time.

There are three methods which are classified as the innovative approach in this research. These methods include the "A+B" method, the incentive/disincentive (I/D) method, and the lane rental method. Discussion of these methods is as follows.

The "A+B" method

Unlike conventional bid methods which concern only the total costs of project work, the "A+B" method takes both cost and duration of the project into consideration. This method awards a project to the low bidder based on the sum of the

dollar amount of all work to be performed under the contract and the total dollar amount of Daily Road User Costs (DRUC) assigned by the owner. The project duration estimated by the low bidder thus becomes the project contract duration. The formula utilized to calculate the project total bid price is:

    Bid Price = A + B x DRUC

        Where,
            A: costs of performing project works
            B: total project duration
         DRUC: Daily Road User Costs

Several advantages of the "A+B" method have been addressed by researchers (Herbsman and Ellis, 1992). The following are the most important:

1) Awards contractor's ability to work fast.

2) Forces contractor to plan work ahead and put more burdens on himself.

3) Takes overall project costs into consideration.

4) Does not compress the maximum allowable time.

In addition to the advantages, several disadvantages of utilizing the "A+B" method also have been found which are as follows:

1) Encourages short cuts and thus affects work quality.

2) Limits small contractors.

3) may produce higher costs than actual work entails.

An example of applying the "A+B" method to determine project contract duration is shown in Table 2-3. This example

involves the partial rehabilitation and widening of the I-440 in North Carolina. The original project duration estimated by owner was 793 calendar days. Using the "A+B" method, a savings of 193 calendar days or an amount of $193,000 in combined DRUC and contract administration costs was achieved. This example concludes that the "A+B" method has the ability to significantly decrease the project time.

Table 2-3 Project Bid Tabulation Using the "A+B" Method

Bidder	BCW (A)	RBBCW	BT	VBT (B)	TBA (A+B)	OR
A	$21,482,242.53	1	600	$6,000,000	$27,482,242.53	1
B	$22,815,197.91	2	533	$5,330,000	$28,145,197.91	2
C	$23,723,424.53	4	660	$6,600,000	$30,323,424.53	3
D	$23,318,052.86	3	730	$7,300,000	$30,618,052.86	4
E	$24,773,970.11	5	700	$7,000,000	$31,773,970.11	5
F	$24,987,511.29	6	700	$7,000,000	$31,987,511.29	6
G	$25,060,486.38	7	696	$6,960,000	$32,020,486.38	7
H	$25,247,459.15	8	733	$7,330,000	$32,577,459.15	8

RUC = $1,000/day
BCW: Bid Cost of Work
RBBCW: Ranking by Bid Cost of Work
BT: Bid Time
VBT: Value of Bid Time
TBA: Total Bid Amount
OR: Overall Ranking

Source: Survey response from the North Carolina SHA

The utilization of the "A+B" method for contract duration is increasing in the United States because of its ability to decrease project construction time. Table 2-4 summarizes the status of various projects on which the "A+B" method was used. Analyzing Table 2-4 indicates that the "A+B" method is being

utilized to determine contract duration in 17 states and the results are satisfactory.

Table 2-4   Current Application of the "A+B" Method

STATE	REMARKS
Arkansas	One project, favorable results.
California	Three projects. No results to report.
Delaware	Three projects. First two had favorable results. Third had problem unrelated to the "A+B" bidding.
District of Columbia	Two projects, favorable results.
Idaho	One project, no results to report.
Kentucky	One project, favorable results.
Maryland	Several projects, favorable results.
Michigan	Two projects, too early for results.
Mississippi	Two projects, favorable results.
Missouri	Numerous projects with favorable results.
Nebraska	One project, favorable results.
North Carolina	Ten projects, generally favorable results.
Pennsylvania	Two projects, favorable results.
Texas	Two projects, unfavorable results. "A+B" created friction between the State and the contractor.
Utah	Three projects, favorable results.
Virginia	One project, no results to report.

Source: Federal Highway Administration

The lane rental method

Although the Lane Rental method has been used in the United Kingdom since the last decade, it was not introduced to the United States recently (ENR, 1990). When this method

is applied, the bidder has to submit the total time and period of lane closures in addition to the cost of works performed in the project. SHA provides the rates of lane rental based on different traffic flows. The bidding job is awarded to the low bidder with the lowest overall cost which is the summation of the works cost and the lane closure charges.

The lane rental method was designed to be a disincentive for closing lanes during peak hours. It motivates contractors to finish projects as quickly as possible and in order to minimize the interference to existing traffic flows. According to Bodnar (1988), the lane rental method for highway construction has been successful in demonstrating the scope for reducing the time needed for completion. An example of applying the lane rental method on highway project is shown in Table 2-5.

Table 2-5 Project Bid Tabulation Using the Lane Rental Method

Bidder	Bid Price	Offer Days	DEM[a]	Adjusted Bids	Bid Order
A	$1,593,000	60	14	$1,789,000	3
B	$1,597,000	46	–	$1,597,000	1
C	$1,600,000	49	3	$1,642,000	2
D	$1,698,000	65	19	$1,964,000	4
E	$1,720,000	70	24	$2,056,000	6

[a] Days exceed minimum

Source: Bodnar, 1988

The incentive/disincentive method

Using the incentive/disincentive (I/D) method to reduce project construction time is very popular in various SHAs (Bierhan, 1992). The I/D method is best applied to projects that severely impact on the traveling public and the local economy. In an I/D type project, incentive is used as an award to contractor for his early project completion while disincentive is a make-up charge for the extra costs to the traveling public and SHAs because of the delay of completion. The total amount of I/D posted on the contractor is determined by the daily I/D rates and the project completion date.

The incentive rate must be sufficiently beneficial to the contractor to encourage him to accelerate construction work and thereby complete the project ahead of schedule. The disincentive rate should be great enough to discourage to the contractor form delaying a project completion. In most cases, the same rates are utilized. If different rates are utilized, the incentive rate should not exceed the disincentive rate. Meanwhile, a maximum allowable incentive fee should also be set to prevent the contractor receiving an improper large amount bonus in an I/D project.

The daily I/D rates must be carefully evaluated based on the urgency of the project completion or the total cost of the project. If the project completion is critical, a higher I/D rate should be utilized to motivate contractors to speed up work and thereby decrease construction time. An example of

using the total project cost to compute the daily I/D rates is shown in Table 2-6.

Table 2-6   Various Daily I/D Rates Using by New Jersey SHA

Total Project Cost (in million dollars)	Cost per Calendar Day ($/day)
0 - 0.5	$1,000
0.5 - 1.5	$2,000
1.5 - 5.0	$5,000
5.0 - 10.0	$6,000
10.0 - 15.0	$8,000
15.0 - 20.0	$10,000
20.0 - 30.0	$13,000
30.0 - 40.0	$16,000
40.0 - 50.0	$17,000
50.0+	0.03% of TPC[a]

[a]: Total Project Cost

Source: Survey response from New Jersey SHA

Although the I/D method is very successful in reducing project construction time, there are arguments about the use of this method. Some believe that it is worthwhile to spend extra cost to reduce the inconvenience to the travelling public while others think that the price paid to deal with this method is too high. However, it is agreed that the I/D method reduces project contract duration.

In addition to the daily I/D rates, the success of the I/D method also depends upon the generating of a reasonable contract duration. A high contract duration which allows too much time on a project may cause excess bonuses paid to the contractor while a low contract duration which allows too little time on a project may result in unnecessary claims by the contractor.

Using the KBES in the Construction Industry

The KBES has been introduced in recent years in an effort to improve the deficiency in traditional tools. It has been used in several fields of construction engineering and management such as planning and scheduling, updating and monitoring, risk analysis, equipment selection, financial decision, quality control, and project management (Mohan, 1990).

Macher and Allen (1987) concluded that KBES is most effective in the areas in which experience and judgement plays a critical role. There are several features which illustrate the reasons why construction engineering is suitable for the application of the KBES. Among the most important ones are listed as follows.

1) construction is an experience-based industry,

2) construction decisions must be made quickly,

3) construction decisions involve management issues,

4) construction project is nonrepetitive, and

5) construction decisions are qualitative and need heuristic approaches.

Applying the KBES for Construction Planning and Scheduling

Over the past few years, many KBES for planning and scheduling have been proposed to the construction industry. These include systems for schedule updating, schedule analysis, construction planning, activity duration estimation, project network generation, and prediction of time of construction.

Among these KBES, some were generated by using expert system shells such as PC+ and GURU while others were developed applying programming languages such as Lisp and Prolog. An investigation of existing KBES employed in construction scheduling and planning was made. The following is a brief discussion of the results of the investigation.

CASCH

CASCH is a prototype expert system developed in KEE. The system can be used to typical mid-rise commercial buildings. CASCH receives general information about a specific building and produces activities, sequences activities, and establishes preliminary durations. CASCH uses object-oriented and rule-based knowledge representation tools to state sequencing rules (Echeverry et al., 1991b).

CODES

The Construction Duration Estimating System (CODES) was developed to estimate the project duration for residential and office mid-rise buildings (Sun et al., 1991). This system is implemented in KnowledgePro written in Turbo Pascal. CODES has the ability to: 1) break down the construction process into major activities, 2) sequence activities logic, and 3) estimate the approximate durations of major activities. In addition, particular project features can be input to CODES to modify the schedules produced by it through an enhancement of the user interface. CODES is also able to generate a barchart-based project schedule.

CONSCHED

CONSCHED was developed for progress scheduling in the construction of modular mid-rise residential buildings with reinforced concrete skeletons (Shaked and Warszawski, 1992). Operation of the system includes entering the project attributes, estimating work quantities, generating activities, allocating time and resources to activities, and determining the schedule. CONSCHED operates in a computer environment that includes PC+ (Personal Consultant Plus) expert system shell, Dbase III system, and PASCAL. The KB of CONSCHED includes a rule base, a data base, and procedures.

The system has some significant strengths over other systems, such as: 1) it requires related information at the preliminary design stage; 2) it provides friendly interaction

with the user to contribute information at every stage; 3) it is effective in terms of its input and storage requirements; 4) it considers various objectives of the user.

CONSAS

    A dual-purpose scheduling system, CONSAS has the ability to analyze and recommend for initial, in-progress or updated schedules (Adeli, 1988). This PC-based product is executed by a combined performance of Personal Consultant Plus shell, Primavera Project Planner and DBASE III Plus. Figure 2-12 depicts the schematic structure of CONSAS.
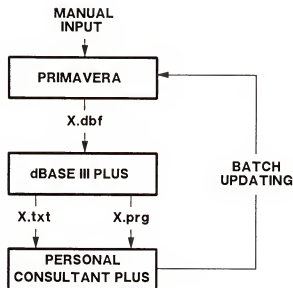
Source: Adeli, 1988

Figure 2-12 Configuration of CONSAS

    In this scheme, separate communication files were constructed to effect the interface between various software

packages. The terminology used defines these communication files as *.XXX. The upgrade of CONSAS is underway; utilizing the ART (Automated Reasoning Tool) as the inference engine to process the knowledge base is being carried out.

CONSTRUCTION PLANEX

Implemented in KNOWLEDGECRAFT, CONSTRUCTION PLANEX is able to generate project activity networks, cost estimates, duration estimates for the foundation and frame construction of a modular building. Activity sequencing in PLANEX is specified through the use of codes which are tied to a Masterformat (CSI) classification of the elements to be installed. In order to manipulate the system, users have to input the detailed description of design building elements.

Like other KBES, CONSTRUCTION PLANEX has three essential parts- the Context, the Operators, and the Knowledge Base. PLANEX also contains a menu-driven interface and a Knowledge Source Acquisition Module. It is the first knowledge-based system that emulates the complete construction planning process (Hendrickson et al., 1987b).

ESCHEDULER

Expert Construction Scheduler (ESCHEDULER) is a rule based hybrid prototype expert system (Moselhi and Nicholas, 1990). This system is mainly made up of three components which includes a project management software- PROMIS, a interface program written in FORTRAN, and a commercial shell-

GURU. A schematic chart of the ESCHEDULER is shown in Figure 2-13.
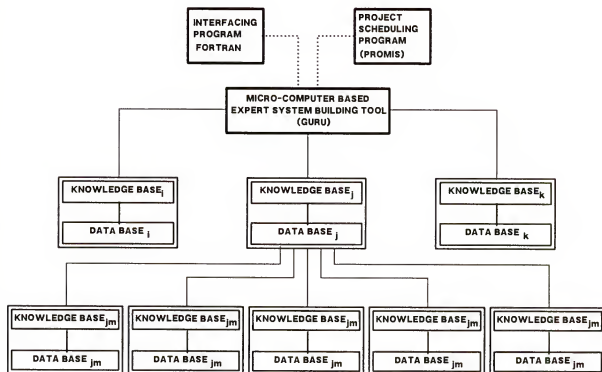
Source: Moselhi and Nicholoas, 1990

Figure 2-13 General Architecture of the ESCHEDULER

System users have to input activity description, duration and related information to execute ESCHEDULER. The system includes five major construction delay factors which are overtime, trade congestion, learning curve, reassignment of labor, and weather. In addition to the solo impact of these factors, the incorporated impact with other factors can also be executed as long as the user quantifies the combined effect of factors.

ESCHEDULER generates two different schedules based on different construction stages. The as-planned schedule is produced first by consulting three knowledge-based ES. The as-possible schedule is then generated by taking the impact of five factors into account. It should be noted that the system relies on both heuristic and algorithmic methodology to manipulate the knowledge bases.

Although activity generation is not addressed, ESCHEDULER has limited abilities to 1) modify user provided activity durations by accounting for some productivity affecting factors mentioned above, and 2) provide a default activity sequence according to pre-established typical sequences (Echeverry et al., 1991a).

LOBEX

Developed by (Arditi and Srigungvarl, 1992), LOBEX is used for the scheduling of high-rise building construction. LOBEX is mainly made up of an expert system shell, the System for Repetitive Unit Scheduling (SYRUS), and DBASE. Additional components such as knowledge acquisition unit, explanation module, debugging facilities, and intelligent interface are also included in this system.

SYRUS is a scheduling software utilizing Line of Balance as the scheduling technique. The expert system shell includes an Inference Engine, a Context, and a Knowledge Base. After receiving project and activity information, LOBEX provides a table of the start and the finish times for each activity at

its first and last unit. A line of balance diagram of critical activities is part of the standard output.

MASON

A rule-based prototype expert system, MASON is developed for the application of a limited range of masonry works. The system can be employed to estimate the duration of masonry construction, to explain various calculations made, and to provide recommendations for alternative crew compositions and technologies.

MASON utilizes the "back-chaining" problem-solving approach (Martinelli, 1986). However, it also could be implemented as a forward-chaining system based on job characteristics or using a semantic net. MASON is implemented in the OPS5 programming language (Hendrickson et al., 1987a).

PLATFORM

PLATFORM is a prototype expert system for the updating of limited activity schedules for design and construction of concrete off-shore oil drilling platforms (Levitt and Kunz, 1985). This system is implemented in KEE program environment.

PLATFORM does not address the generation of construction schedules; instead it focuses on monitoring and updating a given schedule. PLATFORM updates the initial project schedule by recording the actual duration of completed activities. However, the user may override some of the system's recommendations in the updating process.

PLATFORM also provides limited changes to network topology by explicit storing alternative subnetworks for each major activity. Depending on the soil condition, the system selects one of these subnetworks while creating the final project network.

<u>TIME</u>

A rule-based expert system, TIME was developed by using Prolog2 (Gray and Little, 1986). This system was developed to evaluate various construction methods, designs, and processes to determine their effects on time and cost of construction. The breakdown of the construction project in the system is based on the type of work, operationally significant function, and operationally significant location.

Activity duration estimates are inferred sequentially from knowledge about the technology of each construction operation, and are then adjusted by knowledge of preceding work operations, the size of the buildings, and the availability of labor and equipment resources.

<u>X-PERT</u>

Functioning under WINDOWS 3.0, X-PERT was developed to produce a scheduling network for building projects (Miresco, 1992). Activities in the system are classified and structured using the Work Breakdown Structure approach. X-PERT is capable of continuously modifying the information existing in the knowledge base. In addition, users have the option to

add, delete or modify the existing construction sequences of the knowledge base and to customize them to their needs.

The most important feature of this system is that the knowledge is stored graphically. By using WINDOWS software, the user does not have to be an expert in construction engineering to prepare the input for a scheduling job.

Summary of KBES Review

Various KBES developed for construction scheduling have been addressed in the previous sections. Table 2-7 provides an overview of several KBES applied on construction fields. It is apparent that majority of the KBES with a rule-based knowledge-representation scheme are implemented by utilizing commercial KBES shells.

In addition, the application domain and the ability of duration estimation of these KBES is further summarized in Table 2-8. It is apparent that expert system commercial shells have an edge as implementing environments.

Expert system commercial shells afford powerful, high-level programming environments for developing interactive planning systems. According to Levitt, Kartam, and Kunz (1988), expert system commercial shells are much better suited for a range of construction project planning and scheduling than highly specific or pure expert system.

Table 2-7   Summary of Various KBES Used for Construction
            Planning and Scheduling

KBES	SHELL/PROG LANGUAGE	KNOWLEDGE PRESENTATION
CODES	KnowledgePro	Rule-Based
CONSCHED	PC+	Rule-Based
CONSAS	PC+	Rule Based
CASCH	KEE	Object-Orient.,Rule-Based
PLANEX	KnowledgeCraft	Frame-Based
ESCHEDULER	GURU	Rule-Based
LOBEX	N/A	Rule-Based
MASON	OPS5	Hierarchical Rule-Based
PLATFORM	KEE	Frames & Rule-Based
TIME	Prolog	Rule-Based
X-PERT	N/A	Rule-Based

Source: Mohan, 1990; Arditi and Srigungvarl, 1992; Miresco,
1992.

Table 2-8   General Characteristics of Surveyed KBES

NAMES OF KBES	APPLICATION DOMAIN OF CONSTRUCTION	CAPABILITY OF DURATION ESTIMATION
CODES	Mid-rise residential and office building	Activity duration
CONSCHED	Modular mid-rise residential building	Project duration
CONSAS	Can not be determined	Scheduling analysis
CASCH	Mid-rise commercial bldg	Project duration
PLANEX	Foundation and frame activity of modular high-rise building	Activity duration
ESCHEDULER	Building Construction	Project Duration
LOBEX	High-rise building	Project duration
MASON	Masonry construction	Activity duration
PLATFORM	Major activity of design and construction of oil drilling platform	Update scheduling
TIME	Mid-rise building	Based on quantity
X-PERT	N/A	Schedule network

Source: Mohan, 1990; Arditi and Srigungvarl, 1992; Miresco, 1992.

Conclusions of Literature Review

In this chapter, current practices of contract duration determination in highway construction and application of KBES in construction scheduling and planning are explored. Several conclusions based on the investigation are:

1) Although the use of the innovative approach has grown recently, the production rates method still dominates contract duration determination for highway construction projects.

2) CPM and barchart are SHA's favored scheduling techniques when utilizing the production rates method to estimate contract duration.

3) The PTE method is not suitable for application in large or complex projects. However, this method can be a handy tool for the determination of contract duration of small or simple projects.

4) Although KBES has been applied in various fields of construction engineering, no KBES has been developed as yet to estimate contract duration for highway construction projects.

CHAPTER 3
FACTORS AFFECTING CONTRACT DURATION DETERMINATION

Introduction

Highway construction is different from most other categories of construction because of the type of equipment required and field material involved. Highway projects are usually characterized by large numbers of heavy equipment such as power shovels, scrapers, draglines, large cranes, heavy-duty haulers, paving plants and other similar equipment. The scope of work is generally wide, including clearing and grubbing, excavation, backfill, aggregate production, subbase and base, paving, bridges, drainage structures, traffic signs, lighting systems, curbs and gutters.

Contract durations can not be simply determined by work items, work quantity and work production rates because they involve a wide variety of parameters. To determine realistic project contract durations, schedulers should consider various factors which affect the proceedings of the project.

In this chapter various factors affecting contract duration determination are discussed. These selected factors are based on various publications, guidelines, and information gained from scheduling experts in highway construction.

Factors Affecting Contract Duration Determination

General Statement

There are a number of factors affecting contract duration determination for highway construction. These factors can be called as the contract duration influence factors (CDIFs). The CDIFs may vary from project to project because of the unique characteristics of the individual project.

Herbsman and Ellis (1994) classified the CDIFs into five categories: the project characteristics factors, construction operation factors, economic and legal factors, geophysical factors, and miscellaneous factors. Figure 3-1 displays the categorized CDIFs.

In general, the CDIFs affect contract duration either by reducing work production rates or increasing time for work performance. Measuring the impact of influence factors is difficult because they are interacting with each other. Even within a given scope of work, many of these factors may have different degrees of influence and impact. For instance, both project location and traffic flows affect work production rates. However, there is not clear cut guidance about the specific impact on work production rates for either project location or traffic flow.

In order to investigate the significance of the CDIFs, a nationwide survey was sent to various SHA's in the USA and Canada. Analysis of the survey is summarized in Table 3-1. Further discussion of the CDIFs is presented next.
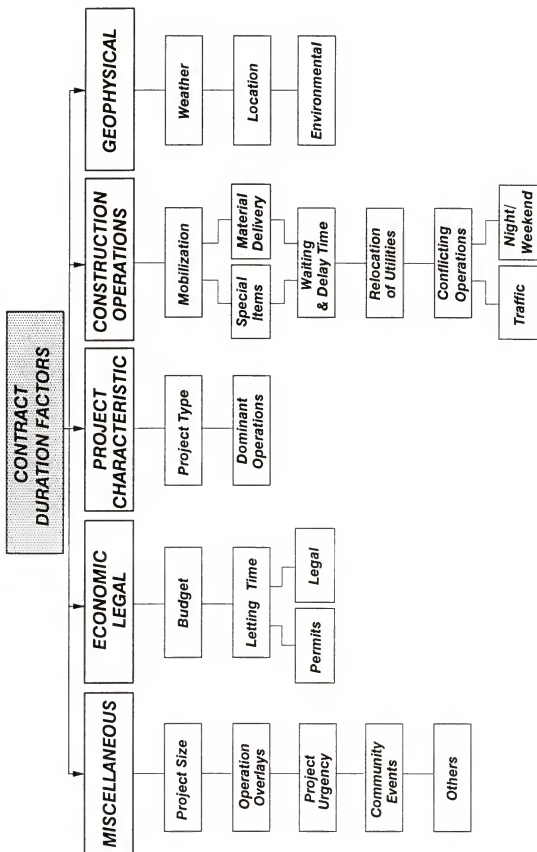
Figure 3-1 Significant Factors Affecting Contract Duration Determination

Table 3-1   Factors Affecting Contract Duration Determination

FACTORS	UNITED STATES																																					CANADA				
	AK	AL	AZ	AR	CA	CO	DC	DE	FL	GA	HI	NH	IA	ID	IL	IN	KS	KY	LA	MD	ME	MI	MO	MS	MT	MO	NJ	NV	OH	OR	RI	PA	SC	TX	WA	WI	WY	AL	MB	NB	NS	SA
Weather & Season Eff.	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Mobilization	X		X		X					X							X								X							X					X					
Special Items	X	X	X	X				X	X	X		X		X			X	X	X	X		X		X			X	X	X	X	X	X		X	X		X			X		
Traffic Impacts	X	X		X	X			X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X				X
Type of Project	X	X	X	X	X	X	X		X	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X	X	X	X	X	X	X
Budget & Payment Ctl.			X		X	X					X	X		X	X						X	X			X	X	X	X	X	X		X	X		X		X	X	X	X		X
Letting Time	X	X		X				X			X		X		X	X	X		X	X	X	X		X			X	X	X			X	X		X		X			X		X
Legal Aspects																																								X		
Utility Relocation	X		X		X	X	X			X	X		X	X	X	X	X		X	X	X	X			X		X	X		X		X	X		X		X	X		X		
Dominant Operations	X		X		X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X			X	X	X	X	X	X			X	X		X		X	X		X		
Location of Project	X	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X	X	X	X		X		X	X	X	X		X	X		X	X	X	X	X	X	X	X
Material Delivery Time	X		X	X		X	X	X	X	X		X	X	X		X	X		X		X				X		X		X	X	X	X	X		X	X	X			X		
Waiting & Delay Time	X								X			X		X		X			X		X	X							X	X		X			X	X	X		X			
Conflict. Constr. Oper.		X		X		X							X	X	X	X	X		X	X	X	X	X	X	X		X		X		X	X	X		X	X	X	X		X		
Various Permits	X				X	X	X			X	X	X	X	X	X	X	X	X	X	X		X			X				X	X		X	X		X	X	X			X		
Night/Weekend Work		X	X		X	X	X			X	X	X	X	X	X		X			X	X	X			X		X		X	X		X	X		X		X	X				X
Environment. Factors	X		X		X		X		X	X	X	X	X	X		X	X		X	X	X		X			X			X	X		X	X		X	X	X			X		X
Others			X						X	X	X	X	X						X															X								

NOTE: X- Considered by SHAs as a factor affecting contract duration determination

Geophysical Factors

Three factors, weather effects, location of the project and environmental factors, are classified as geophysical factors. The following sections address these geophysical factors in detail.

Weather effects

Highway construction projects are defenseless in adverse weather because of their extensive exposure to seasonal variations. Adverse weather results in the delay of construction works, decreased productivity, idle equipment, spoilt materials, increased contingency overheads, and, consequently, higher prices.

Harsh weather has different impacts on different highway construction operations. For example, clearing and grubbing can continue during cold weather while earthwork must be halted during subfreezing temperatures. Table 3-2 indicates the weather impact on various highway construction operations.

According to the survey responses, 98% of SHA's in the USA and Canada consider the harsh weather impacts on contract duration determination. However, the concern of weather impact varies with the geographic location of the state. In Florida, for instance, the weather impact is not an important issue. Thus it is generally ignored when estimating contract duration. In Alaska, weather impact on construction work is taken into special consideration due to the state's harsh weather conditions.

Table 3-2   Effect of Winter Weather Conditions on Highway
            Construction Operations

CONSTRUCTION OPERATIONS	Low Temperature	Rain	Sleet	Snow	Ice	Frozen Ground	Wind
Traffic Handling	L	M	S	S	S	L	L
Layout and Staking	M	S	S	S	S	M	M
Clearing and Grubbing	L	M	M	M	M	L-M	L
Material Delivery & Storage	L-S	S	S	S	S	L-M	L
Excavation	L	S	M	M	M	M	L
Embankment Site Grading	M-S	S	S	S	M	M-S	L
Pile Driving	L	M	M	M	M	M	S
Dredging	M-S	L	L	L	S	L	M
Erection of Coffer Dams	M-S	L	L	L	S	L	L-M
Formwork	M	S	S	M	S	L	L-M
Steel Erection	M	S	S	M-S	S	L	M-S
Placing of Reinforcing Steel	M	S	S	S	M-S	L	L
Mixing and Placing Concrete	S	S	S	M	M	L	L
Curing Concrete	S	M	M	M	S	L	M
Stripping Forms	L	M	M	L	M	L	L-M
Backfill	S	S	S	M	M	M-S	L
Base Placement	S-M	S	M	M	M	M-S	L
Paving	S	S	S	S	S	M	L
Landscaping and Seeding	S	S	S	S	S	S	L
Painting	S	S	S	S	S		M
Fencing	L	M	M	M	M	M-S	L
Lighting	M	M	M	M	M	L	L
Signs	L	M	M	M	M	M	M

Note: S - Severe, M - Moderate, L - Little.
Source: Wall, 1978.

In order to monitor the weather impact on construction work, a monthly working days database based on past weather history ought to be established. The monthly working days should exclude anticipated adverse weather days, holidays and weekends. Table 3-3 shows the available working days in a calendar year in the state of Alabama for three different geographical areas.

Table 3-3   Annual Working Days Utilized by Alabama SHAs

MONTH	DIVISIONS 1,2	DIVISIONS 3,4,5	DIVISIONS 6,7,8,9
January	9	11	14
February	9	11	14
March	16	17	17
April	16	17	17
May	17	18	18
June	17	17	16
July	16	15	14
August	18	17	18
September	16	17	17
October	19	19	19
November	16	17	17
December	8	12	15
TOTAL	177	188	196

Notes: Working days listed above exclude weekends and
        holidays.
Source: Survey responses from Alabama SHA

In order to avoid low productivity, most construction works are suspended during winter period in those states with severe weather. A nationwide survey conducted by Hinze and Coleman (1991) concluded that 27 states in the United States terminate their construction works during winter shutdown periods. Table 3-4 displays various winter shutdown periods utilized by SHAs.

Table 3-4 Winter Shutdown Periods Used by Different SHAs

Winter Shutdown Period	States
1 November – 31 March	NY
1 November – 30 April	AK
15 November – 15 March	ME
15 November – 31 March	IA
15 November – 15 April	MI, MN, ND
16 November – 15 April	MT
1 December – 1 March	ID, OR, UT
1 December – 31 March	CO, CT, IN, KY, NH, SD, VA, WV, WY
1 December – 15 April	VT
1 December – 30 April	OH
15 December – 15 March	MO, NC
15 December – 15 April	RI
16 December – 15 March	DE
16 December – 30 April	IL

Source: Hinze and Coleman, 1991

Although a number of states suspend construction works due to severe weather conditions, only a few states allow project contract duration to be extended because of adverse weather. According to Hinze and Coleman, only eight states (30% of states that suspend construction works during winter shutdown periods) allow contract duration to be extended due to direct implications of adverse weather.

Environmental factors

In the recent years, environmental issues have received significant attention, sometimes even higher than economic issues. Although each state may have different environmental concerns, the problems are resolved prior to the start of construction.

In general, specific restrictions are posted to ensure adequate environmental protection. For example, operations such as in-stream work are prohibited during spawning seasons in North Carolina. In southern Nevada, contractors are given extra time to install fences for the protection of tortoises. In addition, construction work noise should also be limited especially for projects located near residential or business areas.

Location of the project

The impact of project location is usually associated with other factors such as traffic patterns, material delivery, and utilities relocation. Even within the same state, work production rates may vary significantly because of different geographic locations. Table 3-5 displays an example of work production rates with different geographic locations as utilized by the Washington SHAs.

In addition to the project geographic location, the project site location also plays a critical role in the variation of production rates. In urban and metropolitan areas, for example, construction works are interfered with

Table 3-5 Effect of Project Location on Various Production
           Rates

| NO. | WORK ITEMS | UNITS | Daily Production Rates | |
			WEST	EAST
1	Mobilization	Days	3 to 15	3 to 15
2	Clearing & Grubbing	Ac.	1.5	3
3	Stripping	Ac.	1.5	3.5
4	Removing Manhole	Ea.	2.5	2.5
5	Removing Catch Basin	Ea.	4.5	4.5
6	Removing Conc. Inlet	Ea.	6	6
7	Removing Bituminous Pavement	SY	1800	3000
8	Removing Cement Conc. Pavement	SY	600	1200
9	Removing Asphlat Conc. Pavement	SY	1100	2700
10	Removing Cement Conc. Curb & Gutter	LF	1100	1500
11	Removing Ashp. Conc. Curb & Gutter	LF	1900	1900
12	Removing Cem. Conc. Sidewalk	SY	250	730
13	Removing Guardrail	LF	1000	1200
14	Removing Guardrail Anchor	Ea.	6.5	6.5
15	Removing Paint Stripe	LF	1900	1600
	Removing Plastic Stripe	LF	900	500
16	Removing Paint Marking	SY	320	60
17	Removing Plastic Marking	SY	120	50
18	Removing Raised Pav't Markers	Hund.	8.5	3
19	Removing Chain Link Fence	LF	500	800
20	Removing Wire Fence	LF	2100	2700

Source: Survey Response from Washinton SHA

high volume traffic and tight work spaces. As a result, work production rates decrease dramatically. Unlike the projects performed in urban and metropolitan areas, rural projects typically tend to have higher work production rates.

Project Characteristic Factors

Two major factors, type of project and dominate project type, are categorized as the project characteristic factors. A brief discussion follows.

Type of project

Highway construction involves various types of projects such as roadway widening, resurfacing, reconstruction, and new roadway construction, etc. Different type of projects have their own major work items. For instance, major work items of a resurfacing project differ from those of a new roadway project. Furthermore, production rates of the same work item which is performed in different projects may deviate because of the respective complexities and unique characteristics of the projects. Table 3-6 displays various production rates based on different types of projects.

In general, contract duration is determined by each work item with minor adjustments being made for different projects. Simple projects usually need only minor adjustment because of limited complexity while complicated projects certainly demand much more consideration.

Table 3-6 Effect of Different Project Type on Various Production Rates

ITEM	UN	TYPE1	TYPE2	TYPE3	TYPE4	TYPE5
1 Mobilization	Day	10	10	10	10	10
2 Clearing Site (Including Stripping)	Acr	4	4	4	4	N/A
3 Removal of Vertical Curb	LF	N/A	500	250	250	250
4 Demolition of Building	Uni	1	1	1	N/A	N/A
5 Asbestos Clean-Up						
Resident & Small Commerical	Day	4	4	4	N/A	N/A
Large Commerical	Day	10	10	10		
6 Removal of Bituminous Concrete Overlay	SY	N/A	1000	1000	500	150
7 Roadway Excavation or Embankment	CY	2000	500	500	N/A	N/A
8 Wet Excavation	CY	1000	150	150	N/A	N/A
9 Drainage Pipe (Including 1 Structure)	LF	200	100	50	N/A	N/A
10 Reset Castings	Uni	N/A	4	4	4	4
11 Subbase	CY	350	250	150	N/A	50
12 Aggregate Base Course	CY	350	250	150	N/A	50
6 Inches Thick	SF	2000	1500	1000	N/A	250
13 Bituminous Concrete Base of Surface Course	Ton	1000	750	750	1000	50
14 Portland Cement Concrete Base of Surface Course	SY	2500	1000	750	N/A	225
15 Concrete Barrier Curb	LF	400	400	400	300	N/A
16 Concrete Vertical Curb	LF	500	400	400	300	200
17 Concrete Sidewalk	SY	225	175	165	150	150
18 Concrete Conduit	LF	300	200	200	50	50

NOTE: Production rates are per working day unless otherwise indicated.
TYPE1 = New constr., additions or major reconstr. of divided or undivided hwys.
TYPE2 = Rebulding or upgrading existing hihgways.
TYPE3 = Widening (less than one lane) and resufacing existing highways.
TYPE4 = Resufacing existing highways with bituminous concrete.
TYPE5 = Minor construction, or reconstruction of street or hihgway intersections.

Source: Survey response from New Jersey SHA

Dominant project type

Complex highway projects consist of various structures such as bridges, roads, and pipes. In this kind of project, some phases or controlling operations dominate the project contract duration. Thus, identifying the dominant operations of a complex project is important.

The monthly working days may vary for different dominant operations. For example, bridge structures historically get more working days per month than roadway projects. In order to cut down project contract duration, dominant operations can be constructed with roadways simultaneously. Additionally, partial completion dates should be assigned to prevent extending contract duration due to the delay of dominant project.

Construction Operations Factors

Construction operations factors are the factors which have direct impact on the work production rates. Eight factors are classified into this category described next.

Traffic impacts

It is apparent that highway construction works and traffic flows affect each other in most cases. Rehabilitation projects such as resurfacing and widening, in general, are more affected by traffic than new roadway construction projects. Thus minimizing traffic disruption, especially within heavy traffic areas, is one of the major concerns for rehabilitation projects.

Normally, work production rates will decrease if traffic disruption has to be avoided. To respond to the traffic impact on work productivity, the Nevada SHA cuts its work production rates by 20% for works performed under heavy traffic conditions. In addition, methods such as lane rentals and night time work can be used to minimize traffic impact due to construction work.

Relocation of utilities

Utilities relocation is one of operations that may delay project completion time significantly in highway construction. According to Herbsman (Herbsman and Ellis, 1994), the time used for utilities relocation can easily run as 40% higher more than those similar projects without utilities relocation problems.

Normally, utilities relocation is performed by a utilities company. However, contractors can also fulfill the job if the utilities company's schedule is tied up. Ideally, utilities relocation should be finished prior to the project letting. However if it can not be finished before the project starting date, extra time should be assigned based on the utility company's time estimation.

Although utilities relocation is a common item in highway construction, not all state policies agree on giving extra time for it. As shown in Table 3-7 some states have restrictive policies while others are willing to give extra time under some circumstances. In the state of Wisconsin, for

example, coordination of moving and adjustment of underground
utilities is factored into project contract duration as a
special case. On the other hand, Montana allows no extra time
for utilities relocation.

Table 3-7 Policy of Assigning Extra Time for Utilities
Relocation Used by Various SHAs

Polices	States
No time given	MO, DC, DE, NE.
Figuring out	NV.
Extra time given	CA, CO, IN, MD, WA, WY, WI, IA.

Special items

According to the survey responses, fabrication and
delivery of steel structures are SHAs primary concerns in
terms of special items. Extra durations assigned to special
items also vary. For example, the state of Missouri allows up
to 90 days for fabricating after the notice to proceed (NTP).
While in the state of Maryland, a maximum of 150 calendar days
is permitted for fabricating structural steel. Nevada allows
120 calendar days for fabrication and delivery of structural
steel girders to job site.

In general, fabrication contracts are let before the
project is awarded to ensure its timely completion. Although
it is clear that some special items should be taken into
consideration for contract duration estimation, no formal

method is used for the required time calculation. In other words, the estimation of extra time for special items largely depends upon scheduler's experience.

Night/weekend work

Today's travelling public often encounter congestion during rush hours. Therefore, maintaining smooth traffic flow when construction takes place has become more increasingly important.   In order to find spacious time to perform construction works which are prohibited during lengthy rush hours, night or weekend provides a better feasible option.

Although performing construction work during nighttime may reduce daytime traffic congestion, it involves several aspects related to construction works. These aspects include the availability of materials, noise impact, risks to drivers, workers' safety, and quality of the works.

For similar projects, nighttime works in general have lower production rates than daytime works under normal traffic condition.   However, nighttime works will have higher production rates than those of daytime if the construction works are performed in heavy traffic areas (Herbsman and Ellis, 1994). This is specially true for the contractors with substantial night time work experience. Therefore, projects executed mostly during night have shorter contract duration than similar projects performed mostly during daytime in high traffic area.

Material acquisition and delivery

Highway construction projects require massive amounts of specific materials such as aggregates, asphalt, and concrete. The supply of these materials generally is short due to heavy demand in construction peak season. As a result, completion of the project is delayed. Material acquisition gets even more critical if a large number of projects have to be constructed simultaneously within the same area.

There are two ways to overcome material shortage. The first one is the application of "flex time", which gives the contractor flexibility to decide his project starting date corresponding to the shortage situation. Another way to handle the problem is to schedule earlier completion so that the critical phases can be finished before shortages develop.

Unlike urban projects, material delivery for rural projects is usually much more crucial due to longer transfer distance and lack of material sources. To ensure timely material delivery, major structure contracts can be awarded separately.

There is no uniformity for giving time extension due to material delivery delay. In Wisconsin, for instance, contractors are not given time extension with the exclusion of steel fabrication delivery unless material delivery delay gets beyond their control. In Iowa, material delivery time will be taken into consideration when determining contract duration if it has great impact on project duration.

Waiting and delay time

Waiting and delays are incurred for many reasons, not all of which can be clearly defined. Among the most important ones are utilities relocation, embankment settlement, concrete curing, and environmental considerations. In general, no time extension should be given for anticipated delays because they should be handled up front in the special provisions. However if the delays are unforeseen or caused by the owner, extra time should be assigned.

Conflicting construction operations

Performing several projects simultaneously usually introduces a number of conflicts. As a result, project progress is delayed and thereby the completion of succeeding projects is delayed. Therefore, coordination with other projects is always an important issue in multiple highway construction projects. According to survey responses, 60% of the SHAs take conflicting operations into account while estimating contract duration.

Employing working day or calendar day contracts sometimes stimulates the delay of follow-on projects due to relatively minor delays incurred by the first-stage project. In order to evade the damage of conflicting operations, completion date contracts with high rate of liquidated damages should be used.

In addition to the utilization of completion date contracts, several strategies can be used to reduce the impact of conflicting operations. For example, in the state of Iowa,

coordination with all projects is resolved during the contract development phase and incorporated into contract requirements. In Illinois, conflicting operations are checked using Barchart to establish contract duration.

Mobilization and assembly time

Mobilization usually is performed after contractors receive the Notice to Proceed. In general, this effort mainly includes obtaining various permits for project and utilities. In addition, temporary facilities and special equipment such as a concrete plant should also be set up on the job site during mobilization period. Although it is common to allocate particular time for project mobilization, there is no unique criterion to set time allowances. In general, parameters such as project size, complexity and distance of material resources are utilized to evaluate the amount of time allowances. Table 3-8 displays various time allowances for mobilization as used by different SHAs.

Table 3-8   Time Allowance for Mobilization Utilized by Various SHAs

States	Time Allowed
Arizona	15 Calendar Days
California	15 Days, 45[a] Days
Maryland	10 Days
Nevada	5 Working Days
Wisconsin	5 Working Days
Kansas	5 Working Days

[a]- For large jobs

Legal and Economic Factors

Legal and economic factors normally affect the project by delaying work operation instead of decreasing work production rates. The project will be delayed if the involving legal and economic problems are not handled well. In general, legal and economic problems are handled prior to the project construction work start. The following sections address these legal and economic factors.

Budget and contract payment control

In most public sectors, budgets have to be spent during a specified fiscal year. As a result, project contract duration is dominated by the availability of the budget. The situation is specially true for multiple years projects. If, however, the money is budgeted prior to the beginning of construction, such as in the state of California, then budget is not a significant factor in terms of determining contract duration.

The management of budget and contract payment is found to vary according to the questionnaire responses. For example, a contractor gets interest pay if payments are not made within a certain time frame because of budget constraints in Indiana state. Some states such as Nevada allow the contractor to start work prior to the receiving of the notice to proceed while the payment to the contractor is delayed if the budget is not available.

Effect of letting time

Project letting time, in general, does not affect contract duration significantly. However, it is crucial if the project is going to be performed in severe weather areas where the available time for construction is limited due to lengthy winter shutdown. In general, project type has great impact on the length of project letting time. Complex projects usually need more letting time then simple projects. The quantitative effect of project letting time on contract duration is difficult to identify. However, it is capable of increasing by as much as 20% of the contract duration according to Herbsman and Ellis (1994).

The SHA's policies applied to this issue are diverse. For example, project contract duration is not allowed to be modified simply because of the effect of project letting time in the state of Wisconsin. It is, however, taken into account if contract duration is expressed in calendar day in Delaware.

Various permits

Based on the survey responses, 48% of SHAs consider various permits as an influence factor when determining project contract durations for highway construction. Permits, excluding environmental permits, usually are taken care of prior to the start of construction to reduce their impact on contract duration. Normally, SHAs are responsible to acquire various permits. However, contractors have to gain some environmental permits on their own.

Legal aspects

According to the survey conducted by Herbsman and Ellis (1994), legal aspects are not considered a significant factor in the determination of contract duration. However, some projects constructed in environmentally sensitive areas may require special permits which may delay the progress of the project significantly.

Miscellaneous Factors

In addition to the influence factors discussed above, some other factors also affect the determination of contract duration for highway projects. Among these are:

1) Project size, which may vary work production rates as shown in Table 3-9,
2) Flex time, which may affect project completion date,
3) Community events such as festivals, fairs, and races,
4) Project urgency, which may have significant impact on contract duration length,
5) Operation overlays, shown in Table 3-10, which usually dominate contract duration,
6) Review time for related subjects, and
7) Seasonal limitations.

Table 3-9 Effect of Project Size on Various Production Rates

NO.	WORK ITEMS	UNIT	SMALL PROJECTS 0 - 750 M	MEDIUM PROJECTS 750 - 1,500 M	LARGE PROJECTS 1,500 M - Greate	OVERLAY PROJECTS
1	Mobilization	TU	10	12	14	15
2	C & G	TU	5 (lead)	8 (lead)	10 (lead)	
3	Small Struct.	TU	5 (lead)	8 (lead)	10 (lead)	
4	Unclass. Exc.	CY/TU	2500-4000	3500-6000	6000-12000	
5	Embankment (CF)	CY/TU	1500-3000	2000-3500	2500-5000	
6	In-Gr. Mod.	SY/TU	1000	10000	10000	
7	Lime Treat A	SY/TU	8000 (+20TU)	8000 (+20TU)	8000 (+20TU)	
8	Lime Treat B	SY/TU	8000 (+20TU)	8000 (+20TU)	8000 (+20TU)	
9	Lime Treat C	SY/TU	10000	10000	10000	
10	Lime Treat D	SY/TU	15000	15000	15000	
11	Cement Treat	SY/TU	8000	8000	8000	
12	Gran. Mat. (CF)	CY/TU	1000-2000	1500-2000	2000-3000	
13	Top Soil	CY/TU	500	1000	1500	
14	Plating Mat.	CY/TU	500	1000	1500	
15	EC	SY/TU	22200	39000	56000	0.5
16	HB Base	TN/TU	700	850	1000	700
17	HB Leveling	TN/TU				500
18	Trench & Seal J	MI EA FOR SIDE/TU				1
19	Grout. Slabs	HOLES/TU				150-300
20	Rem. RCP	SY/TU				250
21	Clean & Seal Jt	FT/TU				200
22	Prelim. Rolling	TN/TU				2
23	HB Bnder	TN/TU	700	700	850	700
24	HB Surface	MI/TU	500	500	700	500
25	DBST	MI/TU	0.5 (2 lane)	0.5 (2 lane)	0.5 (2 lane)	0.5 (2 lane)
26	SBST	CY/TU	1.0 (2 lane)	1.0 (2 lane)	1.0 (2 lane)	1.0 (2 lane)
27	Sho. Mat.	FT/TU				500
28	RC Curb	FT/TU	100 (min. 5)	200 (min. 5)	300 (min. 5)	100 (min. 5)
29	HB Curb	FT/TU	500	500	500	500
30	Curb & Gutter	FT/TU	100 (min. 5)	200 (min. 5)	300 (min. 5)	100 (min. 5)
31	Traffic Stripe	MI/TU	4 (min. 5)	4 (min. 5)	4 (min. 5)	2 (min. 5)
32	Detail Stripe	FT/TU	2000	2000	2000	2000
33	Lengd paint	SF/TU	500	500	500	500
34	Conc. Base	SY/TU	5000	8000	8000	
35	CP (Plain)	SY/TU	5000	8000	8000	
36	RCP	SY/TU	5000	8000	8000	
37	CRCP	SY/TU	5000	8000	8000	

Source: Survey Response from Mississippi SHA

Table 3-10   Adjusted Factors Used by Maryland SHAs for
             Contract Duration Determination

WORK ITEMS	OVERLAY	COMMITS
OPERATION		
Preliminary/Prep Time	100%	Max. 10 days
Grading	70%	Usually includes drainage
Drainage	0 - 25%	Usually completed during drainage
STRUCTURES		
Excavation	25%	
Piling	25%	
Footing Concrete	25%	
Substructure	75%	
Structure Steel	75%	Min. 150 days for fabrication and furnish structure steel
Superstructure	100%	
Deck Coatings	100%	
PAVING	70%	Resurface = 100%
SHOULDERS	70%	Resurface = 100%
LANDSCAPING	100%	
UTILITIES		
Water, Sewage	0%	
Lighting, Signing, Signals	0 - 50%	
CLEANUP, FINALIZE PROJECT	100%	Maximum 10 days

Source: Maryland SHA, 1984

Summary

The influence factors of contract duration determination have been addressed in this chapter. The questionnaire survey indicated that considerable variabilities exist regarding the influence factors of contract duration. Analysis of the responses did not indicate that any one influence factor has consistent impact in all projects. Instead, the impacts of influence factors, in most cases, are depending on the type of project and conditions of work. Figure 3-2 summarizes the significance of influence factors as weighed by various SHAs.
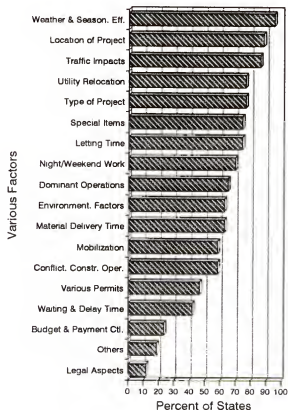
Figure 3-2   Distribution of the Major Factors
Affecting Contract Duration

Identifying project influence factors is relatively easy. However, to quantify the impact of the influence factors is difficult and at times is not possible. Only a few factors such as mobilization and severe weather can be quantified without much difficulty. As a result, the experience and judgement of the scheduling engineer are important in evaluating the impact of influence factors on contract duration determination.

CHAPTER 4
AN OVERVIEW OF THE KBES

Introduction

A knowledge-based expert system (KBES) is a computer program that performs a task traditionally done only by experts or consultants. KBES contrasts with conventional computer programs which are algorithmic in nature, using precisely defined, logical data and formulas. Containing knowledge extracted from experts, KBES manipulate the strategies for problem solving that human experts apply in resolving a problem.

Coming from Artificial Intelligence (AI), KBES is a result of many years of attempting to simulate intelligent problem-solving behavior in a computer program. Research efforts were directed toward the development of general problem solvers instead of specific problem solvers. After many trials, researchers concluded that general problem solvers are weak unless specific knowledge about the problem being solved is added to guide the search for a solution. This inference led to the present KBES (Macher and Allen, 87). The comparison between conventional programs and KBES is displayed in Table 4-1.

Table 4-1 Comparison of the Conventional Programs and KBES

Conventional Program	KBES
Representation and use of data	Representation and use of knowledge
Integration of knowledge and control	Separation of knowledge and control
Algorithmic processing	Inferential processing
Manipulation of large database	Manipulation of large knowledge base
Programmer ensures uniqueness, completeness	Relaxation of uniqueness, completeness
Run-time explanation is impossible	Run-time explanation is a (desirable) characteristic
Numerical process orientation	Symbolic process orientation

Source: Dym and Levitt, 1991.

Basic Structure of KBES

The basic components of a KBES are a knowledge base, a context, an inference engine, and a user interface. Figure 4-1 displays the basic architecture of a KBES. Discussion of these components follows.

Knowledge base. The knowledge base contains facts and a heuristic about a specific domain. The facts are represented by declarative knowledge, and the heuristic takes the form of rules associated with the KBES domain.

Context. The context contains specific information such as problem data, the solution status and action history.
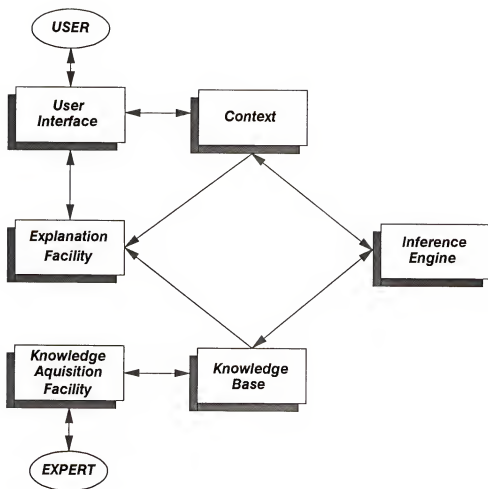
Figure 4-1 Basic Components of KBES

Inference engine. The inference engine contains the control information of the KBES. It adds new facts and rules to the knowledge base and determines the order of scanning and firing the rules.

User interface. This facility allows the user to communicate with the system to create and use a database for the domain problems. The user interface generally is made up of the explanation facility and the knowledge acquisition module. The former explains how solutions are found and why certain questions are asked. The latter facilitates the process of entering knowledge into the knowledge base.

Control Strategies

In a KBES, the inference engine activates communication between the database and the knowledge base. Knowledge is represented by rules and facts, while the inference engine determines how that knowledge should be analyzed. Most rule-based systems reason using either forward chaining, backward chaining, or the combination of these two. The primary difference between forward chaining and backward chaining is the beginning with the data or the goal. A brief description of these strategies is addressed below.

Forward Chaining

The forward chaining strategy is also known as data driven or bottom-up searches. In this type of strategy, the

information in the database is compared with the IF part of the rules in the knowledge base. A particular rule fires in case the IF part of the rule matches the information in the data base. As a result of the firing of the rule, the THEN part of rule is added to the data base.

Forward chaining is simple and easily understandable. However, it can be inefficient since it may involve executing some rules unrelated to the domain problem (Adeli and Suh, 1990). Forward chaining strategy is the most useful in situations where there are many solutions and few input data or facts. Thus it is commonly used for monitoring incoming data and making recommendations to the user based on that new data. The flowchart in Figure 4-2 illustrates the forward chaining logic.

Backward Chaining

The backward chaining strategy is also known as the "goal-driven" or "top-down" strategy. In this type of strategy, the system forms a hypothesis that corresponds to the THEN part of rule(s) in the knowledge base and then attempts to justify it by searching the data base to establish the facts appearing in the IF part of rule or rules. If successful, the hypothesis is established and the expert system reports its results; otherwise, another hypothesis is formed and the inference engine repeats the procedure (Lewand and Bielawski, 1991).

Figure 4-2 Logic of Forward Chaining Reasoning

Backward chaining is more efficient than the Forward chaining since it avoids unnecessary searches rather than consider all rules related to the domain problem. However, it also may create counter-intuitive situations for the user if reasoning is interactive. Figure 4-3 illustrates the backward chaining logic.

Figure 4-3 Logic of Backward Chaining Reasoning

Knowledge Representation

The development of the knowledge base is one of the most important phases of creating a KBES. The developer must determine which type of knowledge representation is to be utilized to represent knowledge in the developing KBES. There are several ways to represent the knowledge contained in the KBES. Some of the most important ones are next.

Predicate Calculus

In this scheme, the real world situation can be written in terms of logical clauses. The knowledge is represented through a programming language such as PROLOG to describe the relationships and facts in the problem domain (Chen, 1987). For example, a statement like "Setting contract duration is the state highway administration's responsibility" can be expressed as:

    "is the (setting contract duration, state highway
         administration's responsibility)".

Semantic Network Representation

A semantic network is represented graphically as a structure of nodes and links. The nodes represent entities (objects) while the links represent relationships between nodes. Similar to frame-based representation, semantic network representation has flexibility for modification and allowing additional new nodes and links. An example of semantic network representation is shown in Figure 4-4.
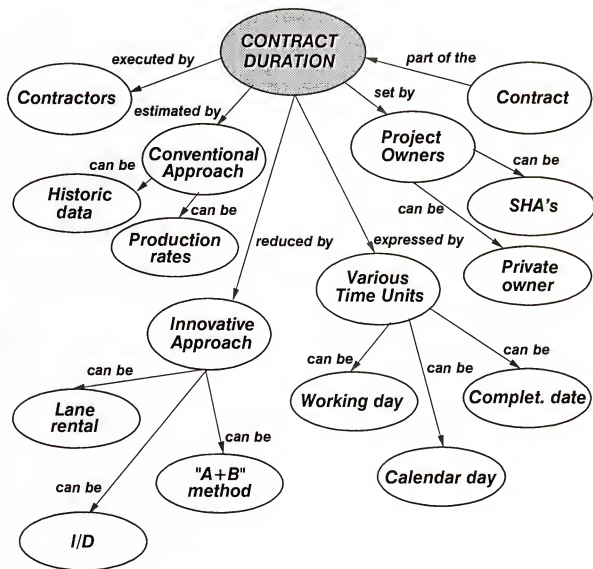
Figure 4-4 Semantic Network Representation

Frame-Based Representation

A frame is a network data structure that is used to describe categorized situations arranged in slots in which different attributes of an object or a piece of information are enclosed. Slots may contain default values, pointers to other frames or procedures. The frame-based representation has advantages in representing sequences of events, and for knowledge acquisition and modification (Adeli, 1988). In addition, knowledge represented by utilizing the frame-based representation is very easy to understand and to organized. Figure 4-5 displays a frame-based representation scheme.

Name of Frame: Knowledge Acquisition	
Method	Interview
FDOT Division	III
Location	Miami, FL
Time	May, 1993
No. of Interveiwee	1

Slots   Fillers
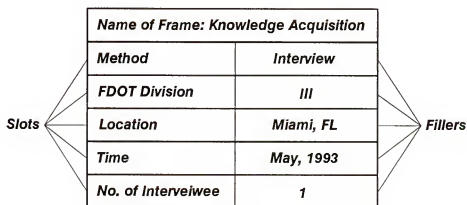
Figure 4-5   Frame-Based Representation

Rule-Based Representation

The rule-based representation, commonly known as the production system, is the most widely utilized representation scheme of representing knowledge employed in KBES. This type of representation considers the knowledge base as a set of rules which are encoded in IF-THEN format.

In rule-based representation, it is not necessary to specify the rules in the order in which they are to be considered. The inference engine provides the underlying strategy for identifying the rules that are eligible to be executed and the selection of one of these rules. An example of the rule-based representation is shown below:

```
IF
     The method used to estimate contract duration is
     Parametric Time Estimating method
and  The project location is within an urban area
THEN
     The adjusted factor due to the impact of project
     location is 1.10
ELSE
     The adjusted factor due to the impact of project
     location is 0.9
```

Blackboard Representation

The blackboard model is based upon the separation of the knowledge base from knowledge sources, and the utilization of a blackboard as a context. The blackboard serves as the location for posting communications between knowledge sources as well as the repository for the current state of the problem solved (Macher and Allen, 1987). Figure 4-6 displays the blackboard representation scheme.
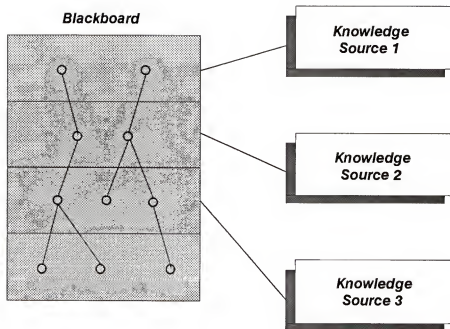
Source: March and Allen, 1987

Figure 4-6 Blackboard Representation

The Strength and Shortcomings of KBES

Some of the fundamental characteristics of a KBES are shown as follows (Macher and Allend, 1987; Terry, 1991):

1) The domain knowledge and the control knowledge are implemented separately;

2) The knowledge used to solve the problem can be expressed in primarily symbolic terms rather than primarily numerical terms;

3) The implementation of the KBES results in a transparent representation of the knowledge and the process that uses the knowledge; and

4) A KBES contains human expertise and judgment through the use of heuristic and compiled knowledge.

Several advantages of KBES compared to human experts were noted in several articles. Among these advantages are:

1) They do not display biased judgments beyond their programming;

2) They do not jump to conclusions and always attend to details;

3) They are always available as long as the machine is working properly;

4) They are easy to reproduce and distribute throughout an organization;

5) They can partially substitute for the real expert in training situations.

There have been widely varying expectations about the ability of KBES. Some limitations should be recognized for these tools (Terry, 1991; Issam, 1989):

1) KBES can not reason broadly over a field of expertise;

2) KBES do not learn;

3) KBES lack common sense;

4) KBES are constrained by both software and hardware;

5) KBES have difficulties in capturing rare expertise;

6) KBES cannot totally replace people;

7) KBES cannot take the place of judgment;

8) KBES can handle only a very narrow domain area; and

9) Their performance declines rapidly when problems grow large.

The KBES Shell

A KBES shell is developed to facilitate the building of a KBES. A KBES shell includes an inference engine, an empty knowledge base, and a user interface. Since shells contain specific representation methods and inference mechanisms, they are generally less flexible than AI language such as LISP and PROLOG.

The primary functions of a KBES shell are to: 1) develop the knowledge base, including adding, modifying, deleting, and generally maintaining the rules and facts in a very user-friendly way; 2) provide an efficient inference engine; and 3) report the reasons and final outcome.

KBES shells enable developers to focus on the knowledge representation instead of the programming details or complex inference strategies. This not only makes building KBES easier, it greatly speeds the prototype system. Fig 4-7 shows the typical features of KBES shells.
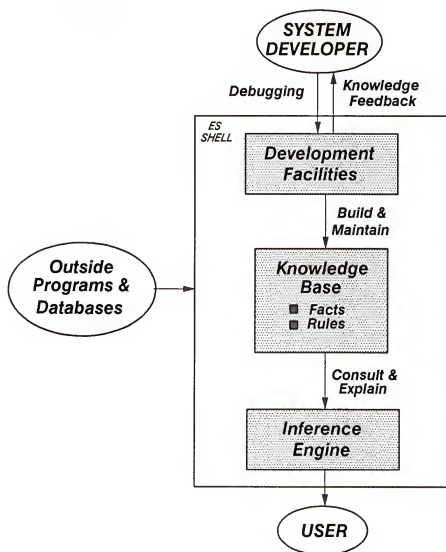
Figure 4-7   General Architecture of a KBES Shell

Steps in Developing a KBES

It is not difficult to develop a KBES by utilizing the commercial shells. There are certain steps to be followed for the development of KBES. However, the steps employed vary, depending upon the characteristics of the problem and other related factors. Basically, each step in the series modifies and refines the work completed in the previous steps. Figure 4-8 shows the major steps utilized in developing a KBES.
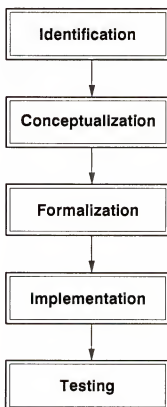
<u>Source</u>: Hanna, Willenbrock and Sanvido, 1992

Figure 4-8 Phases of Developing KBES

As shown in Figure 8, there are five steps in developing a KBES. The detailed descriptions of these steps are presented next.

Identification. The first step in developing a KBES involves specifying the problem characteristics, finding available resources, and setting goals for the entire project. Identifying various potential solutions is essential to assure the sufficiency of the available resources for the domain problem. Recognizing the goals to be accomplished is necessary in this step.

Conceptualization. Key attributes of the task and its domain are clarified in this step. Attention is given to knowledge representation. Communication between the system developer and domain experts is maintained during this period.

Formalization. In this phase, a formal model is developed within the selected tool or framework. The formal model is generated to decide the system representation scheme, the necessary attributes, and their relationships.

Implementation. In this step, the formalized knowledge from the last step is employed to develop a prototype KBES utilizing appropriate tool such as programming languages and commercial shells. Modification are done in accordance with the results of the prototype system.

Testing. The final step in developing a KBES is the testing of the developed prototype system by using case studies. The major purpose of this step is to evaluate the

efficiency of the prototype system. Further improvements of the prototype system are carried out based on the testing results. The system refinement should continue until the system conforms to the standard set by the domain experts.

Summary

KBES is powerful. However, they are not the only answer to all practical problems. Neither they are the panacea for all problems. Instead, KBES can only solve complex problems in a certain domain. The most important requirement for using the KBES for a given problem is that there must be human experts who will provide their expertise. In addition, the primary sources of the expert's knowledge must be judgement and experience.

In this chapter, the fundamental features of KBES have been reviewed. Various knowledge representation schemes also have been introduced. The following chapter describes the knowledge acquisition procedure for developing the KBES for contract duration determination.

CHAPTER 5
KNOWLEDGE ACQUISITION FOR DEVELOPING A KNOWLEDGE-BASED
EXPERT SYSTEM FOR CONTRACT DURATION DETERMINATION

Introduction

Although a KBES consists of different elements, the success of a KBES is heavily dependent upon one element, its knowledge base. A reliable knowledge base is obtained through the successful knowledge acquisition, a process carried out by the system developer.

Knowledge acquisition for a developing KBES is not complex but the process requires considerable time. Several tasks have to be accomplished during the knowledge acquisition process. These tasks include: 1) designing the knowledge base by determining the suitable knowledge required; 2) selecting domain experts to act as sources to enlarge the knowledge base; and 3) effectively extracting the correct knowledge from the selected domain experts (Cohn, 1988).

The goal of knowledge acquisition is to gather valuable information for the selected knowledge-based expert systems. This goal can be achieved by performing tasks including: 1) transforming formless knowledge into formalized concepts, rules, and facts, 2) representing the formalized knowledge in

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a system that is understood by the knowledge-based expert system (Echeverry, 1991b).

It is nearly impossible for the system developer to completely understand the expertise and the strategies used by experts to solve domain problems. Therefore, collecting the expertise and knowledge from domain experts becomes an essential task for the system developer.

In this chapter, knowledge acquisition for EXCONDD (knowledge-based Expert system for CONtract Duration Determination) is addressed. In addition, an overall view of the knowledge acquisition process is also depicted.

Knowledge Acquisition Approaches

Due to a number of issues involved with the acquisition process, such as how, when, and where to gather the knowledge, the system developer plays a critical role in acquiring and organizing the knowledge. Numerous approaches have been used for knowledge acquisition. Among the most important ones are interviewing and observation (McGraw and Harbison-Briggs, 1989). The discussion of the two techniques follows.

Interviewing

Interviewing is perhaps the most widely utilized approach for knowledge acquisition. Interviews are conducted by identifying experts and questioning them, or by getting a group of experts to talk to each other and recording their

discussion. The collected answers or discussions are then further analyzed and organized in order to fit the selected KBES shell.

Interviewing can be unstructured or structured. General questions without specific scopes are asked during the unstructured interview. Particular domain questions are asked in structured interviews. The unstructured interviews are performed before structured interviews are conducted. Thus the unstructured interview is very important in the early phase of knowledge acquisition, while the structured interview plays an primary role in the completion of the knowledge base.

Observation

The observation technique of knowledge acquisition relies not only on personal interviews with domain experts, but also on observation their work if performance, and studies of their problem-solving behavior. When utilizing this technique, the domain experts are requested to provide procedural commentaries about their work performance. The system developer records and analyzes the commentary in order to obtain a clear picture of the problem-solving strategies used by domain experts.

This technique is especially useful if the domain experts are not able to provide clear articulated answers to the domain problems. In addition, it also provides an opportunity for the system developer to understand the influence factors that affect experts in decision making.

Types and Sources of Knowledge

There are two major different types of knowledge: public knowledge and private knowledge (Lenat, 1982). Public knowledge typically is considered static, and can be found in textbooks, journals, and other written reference sources. Private knowledge includes all the knowledge which is excluded in the published literature. Private knowledge also contain rules of thumb which are defined as collections of attributes and corresponding values that include various kinds of conditions and actions.

Several sources of expertise are used to collect the knowledge required for the developing system. These sources include: 1) publications, mainly consisting of those reviewed in Chapter two, 2) guidelines used by SHAs, and 3) scheduling experts who take charge of contract duration estimation. Figure 5-1 provides an overview of various knowledge sources utilized for system development. These sources of expertise are further reviewed as follows.

Figure 5-1 Knowledge Sources for EXCONDD Development

Publications

A literature review was carried out to examine existing publications which addressed subjects related to contract duration determination were found. Of these research papers published by the Transportation Research Board (TRB) are important sources of information. In addition, several articles in the ASCE Journal of Construction and Management provided some valuable information regarding contract duration determination. The literature review indicated that existing publications provided only limited information. Thus other sources, described next, were utilized for the development of EXCONDD.

Guidelines

According to the survey responses, most SHA's have their own guidelines for contract duration determination. Despite having been developed by different SHA's, these guidelines have similar contents. In general, SHAs guidelines provided more detailed information than that provided by the publications. However, none of these guidelines address the assessment of contract duration influence factors in detail.

Scheduling Experts

The previous sources provided mostly general information which was inadequate for this research. Therefore, other available sources were to be identified for the acquisition of complete knowledge. In this research, scheduling engineers in

each district of the Florida Department of Transportation (FDOT) were identified as the third major source for knowledge acquisition.

Knowledge Acquisition for EXCONDD

When developing a KBES, selecting a proper domain is the very first phase. Following that, knowledge acquisition ought to be carried out by the system developer. Certain phases have to be fulfilled to obtain necessary knowledge for the developing system. The knowledge acquisition procedure used for the development of EXCONDD is displayed in Figure 5-2. A description of each phase follows the Chart.

Familiarization Phase
- Review Literature
- Conduct Unstructured Interviews
- Conduct Nationwide Survey

Elicitation Phase
- Identify Domain Experts
- Perform Structured Interviews

Organization Phase
- Analyze Collected Knowledge
- Organize Collected Knowledge
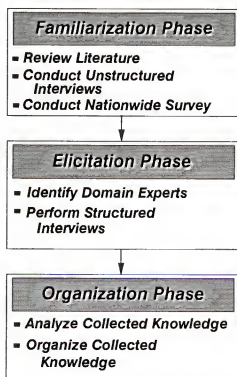
Figure 5-2   Knowledge Acquisition Procedure for EXCONDD

Familiarization Phase

The purpose of this phase is to examine the scope and complexity of the domain problem, thus enables the system developer to get familiarized with the domain problem. The question of whether the initial goals of the research are sufficiently narrow and self-contained is also given consideration on this phase. In this research several actions were completed in the familiarization phase. These actions are described next.

Review literature

Related articles from various journals were studied. A large number of guidelines and available memorandums were also examined. These guidelines and publications were utilized as the basis for the development of a nationwide questionnaire survey. Through the literature review, sufficient information related to the PET method was acquired.

Conduct unstructured interviews

During the development of EXCONDD, two unstructured interviews, one with a state scheduling engineer and another with a district construction engineer, were carried out. The results of the interviews were analyzed and formed the basis for the structured interviews.

Conduct nationwide survey

In order to obtain information on current practices, a questionnaire survey, shown in Appendix A, was drawn up and

sent to each SHAs in the USA and Canada. The questionnaire consisted of four parts: 1) contract duration determination methods, 2) use of innovative approaches, 3) contract duration influence factors identification, 4) identification of key general contractors for further information.

A total number of 43 responses were obtained. Although these responses provided sufficient information related to PET method and "A+B" method, data concerning Production Rates method was inadequate. Therefore, the emphasis on knowledge acquisition process was shifted to collecting the knowledge associated with the production rates method.

Elicitation Phase

The major purpose of this phase is to extract the required knowledge from domain experts and encore the acquired knowledge in a selected development shell. Two primary events performed in the elicitation phase are as follows.

Identify domain experts

The identification of domain experts in general has to be carried before conducting structured interviews. During the unstructured interview, the interviewee, who is a state scheduling engineer, was asked to identify scheduling experts for the structured interview. Seven district scheduling engineers, one from each district in FDOT, was recommended by the state scheduling engineer. These scheduling experts are experienced in contract duration estimating for highway

projects. Some of the experts have more than 30 years experience in dealing with contract duration estimating.

Perform structured interviews

Based on the available information gathered in the previous phase, a set of questions was developed as shown in Appendix B. This questionnaire was used to gather detailed information during structured interviews. A copy of contract duration influence factors, a list of major work items, the general procedure of determining contract duration, and a matrix table containing major work items and influence factors were prepared along with the questionnaire.

Structured face-to-face interviews were performed between April to July 1993. All the interviews were tape recorded to facilitate documentation of all information provided by interviewee. The length of the interviews varied from one and one-half hours to four hours. The average interview length was about two hours. Moreover, several follow-up phone and face-to-face interviews were also made.

The structured face-to-face interviews focused on the adjustment of production rates under various circumstances. Major work items of highway widening projects as well as the procedures of contract duration determination were also identified during the face-to-face interviews. The follow-up interviews were performed to mainly clarify disagreements. Although the collected information had slight inconsistencies, the general guidelines remained the same.

Organization Phase

After completing all interviews, the obtained information such as key concepts and knowledge was organized, structured and then converted into a rule-based representative scheme. In this phase, two major tasks were performed by the system developer. These tasks are described below.

Analyze collected knowledge

After having conducted several interviews, the obtained information was examined to detect conflicts. Several follow-up phone interviews and follow-up face-to-face interviews were made. The major purpose of the follow-up phone and face-to-face interviews was to clarify the existing conflicts. In addition, the experts agreed upon information was finalized and tabulated also.

Several tables were created to summarize the information collected during interviews. The general procedures utilized to determine contract duration for highway construction was summarized in Table 5-1. A matrix table, as displayed in Table 5-2, was developed to depict the interaction between selected contract duration influence factors and major work items of widening projects. Furthermore, the adjusted factors which associate with the characteristics of projects for the parametric time estimating method are also listed in Table 5-3.

Table 5-1 General Procedures of Estimating Contract
           Duration for Highway Construction Projects

==

  1. Determine major work items

  2. Sequence work items

  3. Allocate quantities of work

  4. Decide production rates

  5. Calculate activity working days for work items

  6. Convert activity working days to calendar days

  7. Assign lead time between work items

  8. Assign duration for mobilization

  9. General graphic output

 10. Decide contract duration by rounding off duration

==

Table 5-2 Relationships of Contract Duration Influence Factors and Work Items of Widening Projects

WORK ITEMS	Weather Impact	Traffic Flow	Project Location	Material Delivery	Night Work	Various Permits	Letting Time	Special Items*	Legal Aspects	Waiting & Delay Time	Conflicting Operation	Utilities Relocation	Dominant Proj Type	Environment Concerns
Clearing & Grubbing	X		X		X	X			X		X	X		X
Excavation (Regular)	X	X	X		X	X						X	X	X
Excavation (Borrow)	X	X	X		X	X						X	X	X
Concrete Structure	X	X	X	X	X		X	X				X		X
Concrete Endwall	X	X	X	X	X	X						X		X
Drainage	X	X	X	X	X	X		X			X	X		X
Stabilization Roadbed	X	X	X	X								X		X
Curb/Gutter	X			X	X							X		X
Base Construction	X	X	X									X		X
Milling Exist Pavement	X	X	X				X						X	
Asphalt - Structural	X	X	X	X			X		X				X	
Sidewalk	X		X	X	X		X					X		
Seeding	X			X							X	X		
Sodding	X			X							X	X		
Fence	X			X					X					
Guardrail	X			X				X			X			
Asphalt - Friction	X	X	X	X			X		X				X	
Stripping	X	X												
RPM's	X	X												

* Special Items include fabricated structural members, electro mechanical devices, etc., X: Mutual Interacted

Table 5-3   Adjustment Factors of Project Complexity for the
             PTE Approach

Contract Type	New Construction	1.00
	Reconstruction	0.90
	Overlay & Widening	0.80
	Overlay	0.70
	Safety	0.60
Number of Major Structures	0	0.90
	1-2	0.95
	3-5	1.00
	>5	1.10
Traffic Handling	Minor	0.90
	Minor to Moderate	0.98
	Moderate	1.00
	Moderate to Major	1.08
	Major	1.10
Terrain	Flat	0.95
	Flat to Rolling	0.98
	Rolling	1.00
	Rolling to Mountainous	1.10
	Mountainous	1.15
Location	Rural	0.90
	Rural to Urban	1.03
	Urban	1.10
Special Considerations	Simple Items	0.90
	Unusual Items	1.10
Others		0.90 - 1.10

Organize collect knowledge

Once the knowledge acquired in previous phase has been finalized, it then must be analyzed and organized to fit the selected KBES shell. As a result of employing a rule-based expert system shell for the development of EXCONDD, the collected knowledge must be formatted to conform to this specific representation scheme.

Summary

In this chapter knowledge acquisition in general was addressed. The procedures of knowledge acquisition for developing the prototype system for contract duration were also described. The gathered knowledge was further formatted to conform to the selected KBES shell. After achieving this critical phase, the development of EXCONDD can proceed.

DEVELOPING A KBES FOR CONTRACT DURATION DETERMINATION

Introduction

In this chapter the development of EXCONDD (Knowledge-Based EXpert System for CONtract Duration Determination) is addressed. EXCONDD contains three different modules including the parametric estimating time module, the production rates module, and the "A+B" module. The PET module and the "A+B" module can be applied for all types of projects with no restriction. The production rates module, however, can be utilized only for highway widening and resurfacing projects.

EXCONDD enables the end user to estimate project contract durations for highway construction. This system integrates EXSYS Professional shell, Suretrak Project Scheduler 2.0, and several Lotus 123 spreadsheet files. It can be operated on any IBM PC compatible under the MS DOS environment.

Selecting a Commercial Shell for EXCONDD

In recent years, knowledge-based expert system shells have become the preferred tool for the construction industry (Levitt et al., 1988). The major reason for the KBES shells extensive utilization is because they are suitable for

persons without computer programming ability. To utilize a shell, a system developer only needs to add the knowledge for the domain, and the system is ready to be operated by the end users. Therefore, a KBES shell is always one of the better choices when the ease of utilization and rapid development is desired and the flexibility of the system is not a major priority in terms of developing a specific KBES.

Since a shell is the heart of an integrating system, the capabilities of the employed shell dominate the abilities of the developed system. Therefore, shells should be carefully evaluated in order to select the one with the best fit.

Evaluation of the KBES Shells

Prior to actually developing the system, the utilization of a KBES shell has to be determined. In order to select the best fit shell for the developing system, it is essential to evaluate various KBES shells which are available to the system developer.

A detailed evaluation of six shells which can be run on IBM PC, XT, or AT compatible machines and operated under MS-DOS, was made by the Delta Research Corporation. The purpose was to compare their overall performance (1988). Among these shells, GURU, EXSYS and VP Expert are available in the University of Florida. Thus, the focus of shell selection fell into these three shells.

Referring to Table 6-1, GURU clearly dominated due to its powerful and flexible inference engine and numerous useful

features. EXSYS Professional, in spite of its well rounded capabilities, received slightly fewer points because of its limited control over the inference engine and more constrained programming and system interface features. VP-Expert received the lowest scores in overall performance rate due to its lesser programming flexibility as well as lesser knowledge base capacity. EXSYS Professional was, therefore, determined to be a better choice for the system development.

Table 6-1 Comparison of Various Expert System Shells

CATEGORIES	PTS	GURU	EXSYS	VP EXPERT
Compatibility with AFCCE Hardware/Operating Systems	5	5	5	3
Inference Engine Capabilities	15	15	11	8
Programming Flexibility	15	15	11	5
Knowledge Base Capacity	15	15	15	3
Developer/User Interfaces	10	8	8	8
System Interfaces	10	7	5	8
Processing Speed	10	10	8	10
Vendor Support	5	5	4	5
Documentation	5	4	4	4
Ease of Use/Learning	5	3	4	3
Total	95	87	75	58

Source: Delta Research Corporation, 1988

Overview of EXSYS Professional

Developed by the EXSYS Incorporation Company, EXSYS
Professional has been used to develop various KBES (Ritchie,
1987; Ahmad and Minkarah, 1988; Touran, 1990). EXSYS is
capable of exporting and importing data and can provide
convenient linking to external programs. Also it has the
facility to inform the users why it is asking a specific
question and how it reaches a particular conclusion. In
addition, the system developer can customize screens and
choose available options for the end user. Figure 6-1
displays the overall structure of the EXSYS Professional.

EXSYS can read or write data directly from Dbase III or
Lotus 123 files without physically invoking these software.
It can also invoke any external program that can be executed
under the DOS environment. If the invoked programs are too
large to fit in the computer memory, then EXSYS will save
certain information, take itself out of the memory, run the
external program, reload itself and return to its previous
state.

EXSYS provides the system developer with five different
confidence systems to develop a KBES based on its domain
problems. These confidence systems are depicted in Table 6-2.
Furthermore, EXSYS is capable of handling up to 3000 rules
which represent the domain knowledge in the KBES system. The
rules allow the program to arrive at its conclusions. A rule-
based representation is shown as follows:
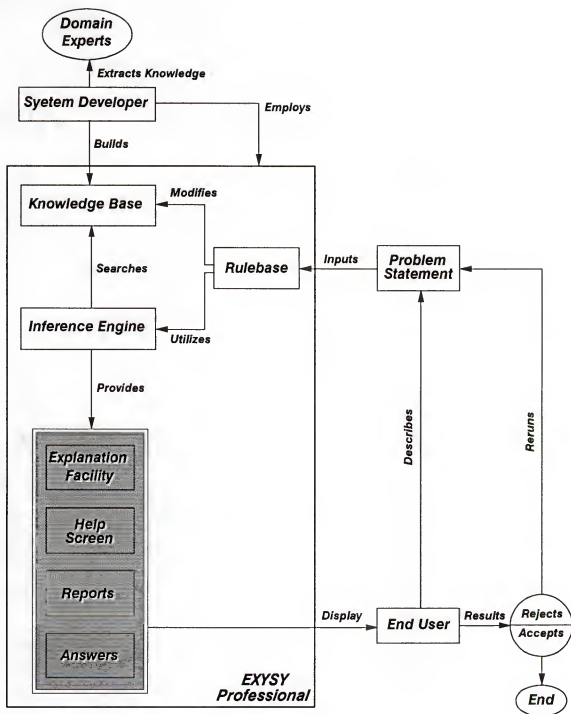
Figure 6-1 Basic Structure of EXSYS Professional

Table 6-2   Different Confidence Systems Included in EXSYS
             Professional

SYSTEM	WHEN TO USE
0 or 1	System does not require confidence factors Choices can be positively selected or rejected in individual rules Ranking of selected choices is not required
0 to 10	Easy to use, very good for beginners Allows confidence factors to be combined, without requiring complex formulas Intuitive for most users to assign confidence factors Most effective general purpose system
-100 to 100	Provides finer resolution of confidence factors Should be used only if statistical data is available with appropriate precision Allows factors to be combined as dependent or independent probabilities
Increment or Decrement	Intuitive, easy to use Good for distinguishing between choices that would receive similar scores in other systems Allows wide point spread in selected items
Custom Formulas	Most flexible and powerful Most complex and most difficult Allows user supplied or derived confidence for qualifiers and variables Should only be used if none of the other systems can handle the problem

Source: EXSYS Inc., 1988

```
IF
        Conditions

THEN
        Conditions
and     Choices

ELSE
        Conditions
and     Choices

NOTE:_____

REFERENCE:_____
```

The explanation facility provided by EXSYS is extremely powerful. For example, whenever the system end user is asked to input a value, he has the option to respond by "WHY" or "?". If "WHY" is selected, EXSYS will display the rules which contain the variable. If "?" is selecting, detailed explanatory texts of the variable input by the developer will be displayed to the user. In addition, EXSYS also enables the user to question how the final solutions are formed. As a result of this inquiry, known data and fired rules to arrive at the solution are displayed. If desired, the user can change the input data and rerun the system again.

Developing the Parametric Time Estimating Module

As indicated earlier, EXCONDD contains three modules including the PTE module, the "A+B" module, and the production rates module. This section addresses the development of the PTE module in detail.

As its name indicates, the PTE module utilizes various related project parameters to determine project contract duration. In addition to the engineer estimate cost, the PTE module developed in EXCONDD uses several parameters such as the Engineering News Record (ENR) cost index, project complexity adjusted factors, and working day equation. Procedures for utilizing the PTE module and the relationships among the involved parameters are described in Appendix C.

Since the PTE module involves complicated calculations, the PTE contract duration calculation template as presented in Table 6-3 was generated to handle these tedious computations. This template can handle projects with an engineer estimate cost of more than $100,000. For projects with the engineer estimate cost of less than $100,000, project contract durations are set by evaluating plan quantities and type of work.

To operate the PTE module, the system end user has to enter the engineer estimated cost and the construction cost index (CCI). The user then provides related project characteristics such as project location, traffic handling, and project terrains. EXSYS exports the engineer estimate cost, CCI, and project complexity adjusted factors to the spreadsheet-base template. Calculations for determining project duration in working days are carried out by utilizing built-in formulas. Once the project duration is generated, EXSYS extracts this value and presents it on the solution

Table 6-3   The PTE Contract Duration Calculation Template

ITEMS	AMOUNT	ITEMS	AMOUNT
Engrs Estimate		Working Days	
Table Estimate		CCIs Ratio	
ENR CCI Rate		Factor Total	
1970 ENR CCI	128.38	No of Factor	

TABLE ESTIMATE		Base Value	Formulas Used to Compute Base Value
Low	High		
$100,000	$250,000		100+(M5-K14)x(25/(M14-K14))
$350,001	$500,000		125+(M5-K15)x(25/(M15-K15))
$500,001	$750,000		150+(M5-K16)x(50/(M16-K16))
$750,001	$1,000,000		200+(M5-K17)x(25/(M17-K17))
$1,000,001	$2,000,000		250+(M5-K18)x(25/(M18-K18))
$2,000,001	$3,000,000		300+(M5-K19)x(25/(M19-K19))
$3,000,001	$5,000,000		350+(M5-K20)x(25/(M20-K20))
$5,000,001	$7,000,000		400+(M5-K21)x(25/(M21-K21))
$7,000,001			450+(M5-K22)x(25/(M22-K22))

Note: CCIs Ratio = 1970 CCI / Current Index

screen to the system end user. Table 6-4 displays the ENR
CCIs from 1967 to 1993.

Table 6-4   Summary of Engineer News Records
             Construction Cost Index

Year	Construction Cost Index
1967	100.00
1968	107.41
1969	100.47
1970	128.38
1971	146.08
1972	161.23
1973	176.63
1974	187.99
1975	205.91
1976	223.43
1977	239.87
1978	258.43
1980	301.44
1981	328.93
1982	355.26
1983	378.56
1984	386.16
1985	389.04
1986	404.80
1987	409.11
1988	420.83
1989	428.81
1990	440.51
1991	450.13
1992	464.06
1993	485.02

Source: U.S. Department of Commerce, 1993

Developing the Production Rates Module

As indicated in the literature review, utilizing daily production rates to estimate contract duration is the most popular method employed throughout the United States. Because of its wide use, the production rates method is included in the developing of EXCONDD.

In highway construction major work items vary significantly with different type of projects. Therefore, including all types of projects in the developing EXCONDD is not practical because of the involving of numerous parameters. To narrow down the scope of this study, the production rates module was developed only for highway widening and resurfacing projects.

Several elements needed to be completed to develop the production rates module. Among these elements are: 1) creating two database files to install major works daily production rates for widening and resurfacing projects, 2) producing a template to store contract duration influence factors (CDIFs), 3) developing a template to calculate contract duration, and 4) selecting a scheduling software.

Success of the production rates module in EXCONDD heavily depends on the integration of these elements. The schematic flowchart of the production rates module is illustrated in Figure 6-2. Detailed discussion of the development of these elements is presented as follows.
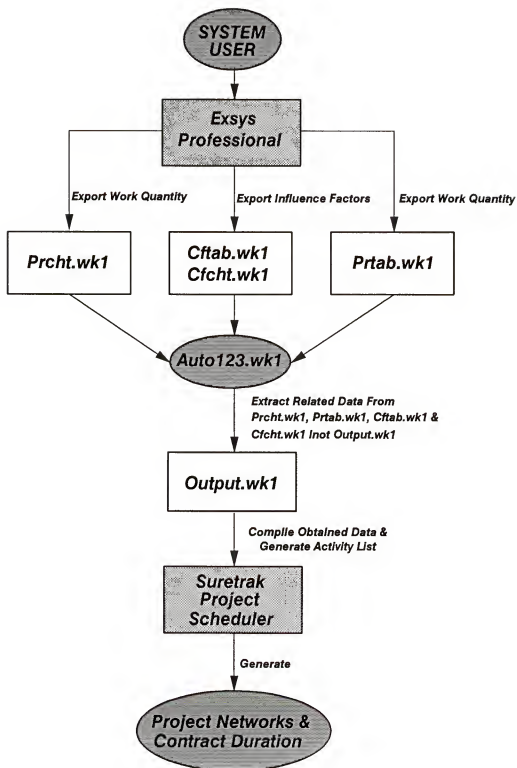
Figure 6-2 The Schematic Flowchart of the Production
Rates Module

Creating the Database Files

Daily production rates of some work items are affected significantly by the total amount of the work while the others are not influenced by the quantity of the work. Work items, whose daily production rates are affected by the total quantity of work, are classified as quantity-associated work items. Work items, whose daily production rates are not affected by the work quantity, are categorized into non-quantity-associated work items.

In general, for quantity-associated work items, the larger the quantity of work the higher the daily production rates are. Regarding non-quantity associated work items, daily production rates are not adjusted simply because of the variety of work amount. Normally, daily production rates of quantity-associated work items are shown by curves or charts. Daily work production rates of non-quantity-associated work items are represented by tables.

For the development of the production rates module, two Lotus 123 spreadsheet templates, displayed in Table 6-5 and Table 6-6, were created to store major work production rates for highway widening and resurfacing projects. The template shown in Table 6-5 is developed to store daily production rates of quantity-associated work items while the template presented in Table 6-6 is generated to store the non-quantity-associated work items daily production rates such as Regular Excavation.

Table 6-5   Template to Store Production Rates of Quantity-
            Associated Work Items and to Compute Unadjusted
            Working Days

ITEMS	AMOUNT	ITEMS	AMOUNT
Record No	1	Code No	201
Work Quantity		Work Item	Excavation (Rugular)
Unit	sy	UWDs	

| Quantity Allocation | | Unadjusted Working | Formula Used to Compute |
Low (1)	High (2)	Days (UWDs) (3)	Unadjusted Working Days (4)
	50000		(42/50000)*Q
50001	90000		42+(12/40000)(Q-50000)
90001	150000		54+(8/60000)(Q-90000)
150001	300000		62+(10/150000)(Q-150000)
300001	1300000		72+(38/100000)(Q-300000)
1300001			110+(1/27500)(Q-1300000)

Note: UWDs- Unadjusted Working Days.
      The amount of UWDs is obtained from colume (3) based

Table 6-6 Template to Store Production Rates of Non-
        Quantity-Associated Work Items and to Compute
        Unadjusted Working Days

CODE (1)	MAJOR WORK ITEMS (2)	WORK UNIT (3)	WORK QUANTITY (4)	DARILY PRODUCTIO RATES (5)	UNADJUSTE WORKING DAYS (UWDs) (6)	MAXIMUM UWDs ALLOWED (7)
101	Clearing/Grubbing	acre		5		
102	Concrete Structure	cy		5		
103	Concrete Endwall	cy		5		
104	Stabilization Roadbed	sy		5000		10
105	Milling Exist Pavement	sy		8000		
106	Drainage	lf		250		
107	Sidewalk	sy		300		
108	Curb/Gutter	lf		600		
109	Seeding	sy		23500		5
110	Sodding	sy		1500		10
111	Guardrail	lf		1500		
112	Stripping	mile		7		

NOTE: (6) = (4)/(5), if (7) < (6) then use (7) as the UWDs of the work item.

Creating the Project Contract Duration Influence
Factors Template

The project contract duration influence factors (PCDIFs)
template was developed to summarize various work contract
duration influence factors (WCDIFs). This template stores the
PCDIFs which are the overall impact of various WCDIFs assigned
by the user. Table 6-7 displays the template of the PCDIFs.

Table 6-7 Summary of Project Contract Duration
Influence Factors

Code (1)	Major Work Items (2)	Project Contract Duration Influence Factors (PCDIFs) (3)
100	Mobilization	
101	Clearing/Grubbing	
102	Concrete Structure	
103	Concrete Endwall	
104	Stabilization Roadbed	
105	Milling Exist Pavement	
106	Drainage	
107	Sidewalk	
108	Curb/Gutter	
109	Seeding	
110	Sodding	
111	Guardrail	
112	Excavation (Regular)	
201	Excavation (Borrow)	
202	Bases Construction	
203	Asphalt-Structural	
204	Asphalt-Friction	
205	RPM's	
206	Fence	

NOTE: PCDIF is defined as the combined effect of
various influence factors on specific work
items. For example, the PCDIF of the
Clearing\Grubbing is the effect of various
influence factors affecting the production
rates of Clearing/Grubbing.

Creating the Major Work Duration Calculation Template

The spreadsheet-based template, AUTO123.WK1, was formed to gather related information input by the user and summarize the results conducted by the production rates module. In this file, several Lotus Macros were developed to extract related information from other spreadsheet templates.

The major work duration calculation template, as shown in Table 6-8, summarizes the information included in DBPRCHT.WK1, DBPRTAB.WK1 and PCDIF.WK1. Analyzing Table 6-8, the quantity of work items and the work item unadjusted working day are transferred from Table 6-5 and Table 6-6 respectively. The value of the adjusted working day equals the value of unadjusted working day multiplies the value of PCDIFs in Table 6-7.

After the adjusted working day of each major work items has been finalized, the information is further refined and summarized in Table 6-9 by utilizing the "Query" function equipped in Lotus 123. In addition, a hardcopy of the project major work list also will be generated by using the built in Lotus Macros.

After obtaining the project work list, the system user has to first of all define the dependencies of the listed work items. Following that, the system user can utilize either the default or any other scheduling software to estimate project contract duration.

Table 6-8 Template of Project Major Work Items and Their Durations

CODE (1)	MAJOR WORK ITEMS (2)	UNIT (3)	QTY* (4)	DAILY PRODUCTION RATES (5)	UNADJUSTED WORKING DAYS (UWDs) (6)	ADJUSTED WORKING DAYS (AWDs) (7)
100	Mobilization					
101	Clearing/Grubbing	acre		1		
102	Concrete Structure	cy		5		
103	Concrete Endwall	cy		5		
104	Stabilized Roadbed	sy		5000		
105	Milling Exist Pavement	sy		8000		
106	Drainage	lf		250		
107	Sidewalk	sy		300		
108	Curb/Gutter	lf		600		
109	Seeding	sy		23500		
110	Sodding	sy		1500		
111	Guardrail	lf		1500		
112	Stripping	mile		6.7		
201	Excavation (Regular)	cy		Refer Record #1		
202	Excavation (Borrow)	cy		Refer Record #2		
203	Base Construction	sy		Refer Record #3		
204	Asphalt-Structural	tn		Refer Record #4		
205	Asphalt-Friction	tn		Refer Record #5		
206	RPM's	each		Refer Record #6		
207	Fence	lf		Refer Record #7		

NOTE: ADWs = UADWs / PCDIF (from Table 6-7)
     *: Quantity

Table 6-9 List of the Project Major Work Items

CODE	MAJOR WORK ITEMS	WORK DAYS	DEPENDENCY	TYPE
100	Mobilization	10		
101	Concrete Endwall	3		
103	Stabilization Roadbed	4		
106	Drainage	2		
109	Seeding	3		
110	Sodding	7		
111	Guardrail	3		
201	Excavation (Regular)	11		
203	Base Construction	14		
204	Asphalt-Structural	6		
205	Asphalt-Friction	6		
206	RPM's	3		

Selecting a Scheduling Software

Based on the survey responses, barchart and CPM are the most extensively utilized scheduling techniques for contract duration estimating. In general, barchart is used in simple and relatively small projects while CPM is utilized for large scale and complicated projects. In EXCONDD, a scheduling software with barchart and CPM needs to be used to activate the production rates module. The major considerations with selecting software are, the abilities of handling different types of dependencies such as finish to finish (FF), finish to start (FS), and start to start (SS).

After evaluating existing scheduling software, Suretrak Project Scheduler 2.0, marketed by Primavera Systems, Inc., was chosen as the most suitable for EXCONDD. This scheduling package is a comprehensive project control software. It is capable of producing various graphic outputs such as barchart, logic diagram, and time scale diagram. It has the ability to export data to Lotus 123 as well.

Developing the "A+B" Module

The third module included in EXCONDD is the "A+B" module. The module provides the option of employing the innovative bidding on the time and cost contracting approach. To use this module, the system end user is asked to input the name, duration and bid cost of individual contractor. The module then compiles the information provided by the system end user

and outlines the lower bidder based on the "A+B" approach. The Name of the lower bidder, total duration, and total cost estimated by the lower bidder are displayed on the system run-result screen. The "A+B" module developed in EXCONDD is able to handle up to ten bidders. However, its capabilities can be reinforced to consider more bidders by adding extra rules.

Forming the Decision Trees for EXCONDD

Decision trees are utilized to graphically convert the obtained information. In general, decision trees are formed before formatting the collected knowledge in order to fit the selected shell. There are two decision trees which are formed to summarize the collected knowledge for the development of EXCONDD.

The information included in Table 5-3 was converted into Figure 6-3 which is a two-level-depth decision tree for the PTE module. The first level of the tree represents project complexity adjusted factors. A total number of seven project complexity adjusted factors are recorded in the tree. Each factor is further divided into several categories as shown at the second level of the figure.

Another two-level-depth decision tree was constructed to contain the obtained information for the production rates module. The first level of the tree includes various CDIFs while the second level of the tree represents the impact of each influence factor as shown in Figure 6-4.
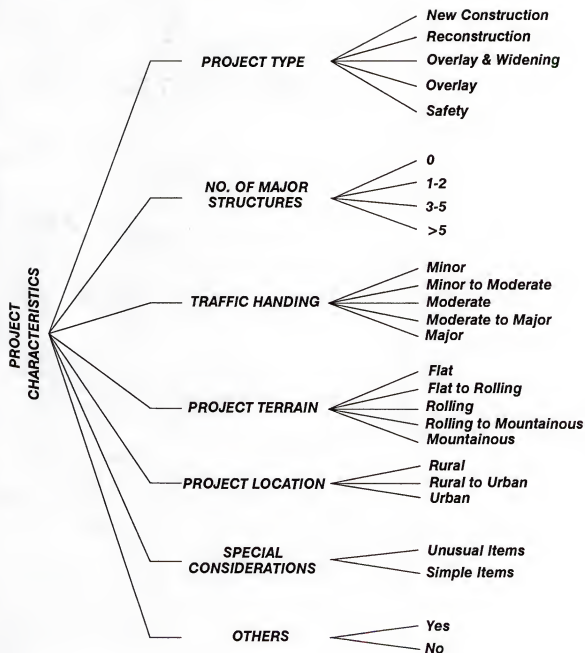
Figure 6-3 The PTE Module Decision Tree
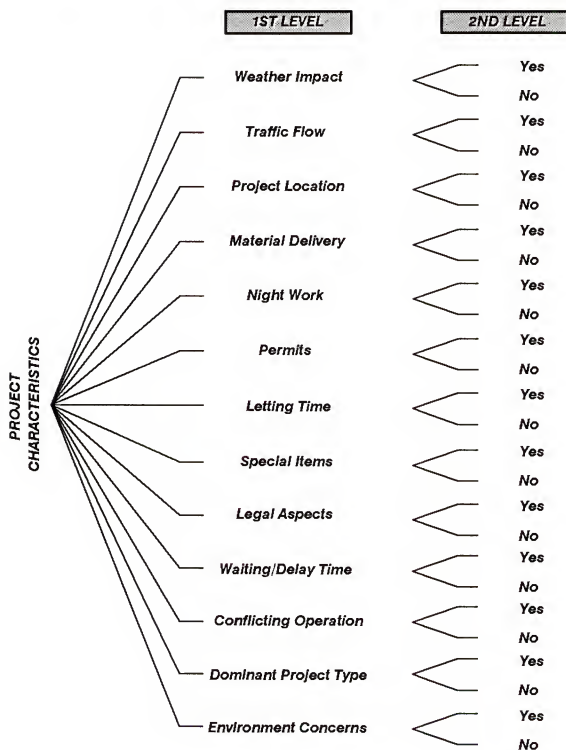
Figure 6-4   The Production Rates Module Decision Tree

Representing the Knowledge Contained in EXCONDD

After finalizing and organizing collected knowledge, the knowledge needs to be converted to fit the selected KBES shell. Since EXCONDD employs EXSYS as the development tool, the composed knowledge was formatted to rule-based representation, which is the formation of knowledge representation of EXSYS.

Various CDIFs and major work items of highway widening projects were tabulated in Table 6-10. In this matrix, the columns represent major work items, and the rows represent various CDIFs. Cells with shadows represent a particular CDIF that basically has no impact on a specific work item. For example, the matrix cell of the Conflicting Operation and Clearing & Grubbing is shadowed since there is no interacting between them.

Two examples are provided that explain converting knowledge to rule-base representation. The first rule illustrates the rule-based representation for the production rates module while the second rule depicts the PTE module.

Rule 1:

```
    IF
        The module of estimating contract duration is
        Production Rates
    and Weather is an influence factor for contract duration
        estimating
    and [Qc]>0
    THEN
        [Wc] IS GIVEN THE VALUE [WC]
    ELSE
        [Wc] IS GIVEN THE VALUE 1
```

Table 6-10 Variables Assignment for Influence Factors Affecting Work Production Rates

CDIFs / WORK ITEMS	Qty Factor	Comb Weather Factor	Weather Impact	Traffic Flow	Project Location	Material Delivery	Night Work	Various Permits	Letting Time	Special Items*	Legal Aspects	Waiting & Delay Time	Conflicting Operation	Utilities Relocation	Dominant Proj. Type	Environment Concerns
Clearing & Grubbing	Qc	Fc	Wc		Oc		Nc	Pc			Gc		Cc	Uc		Ec
Excavation (Regular)	Qv	Fv	Wv		Ov		Nv	Pv						Uv	Dv	Ev
Excavation (Borrow)	Qw	Fw	Ww		Ow		Nw	Pw						Uw	Dw	Ew
Concrete Structure	Qy	Fy	Wy	Ty	Oy	My	Ny		Ly	Sy				Uy		Ey
Concrete Endwall	Ql	Fl	Wl	Tl	Ol	Ml	Nl	Pl						Ul		El
Drainage	Qd	Fd	Wd	Td	Od	Md	Nd	Pd		Sd			Xo	Ud		Ed
Stabilization Roadbed	Qg	Fg	Wg	Tg	Og									Ug		Eg
Curb/Gutter	Qt	Ft	Wt		Ot	Mt	Nt					At		Ut		
Base Construction	Qb	Fb	Wb	Tb	Ob	Mb								Ub		Eb
Milling Exist Pavement	Qm	Fm	Wm	Tm	Om	Mm	Nm								Dm	
Asphalt - Structural	Qs	Fs	Ws	Ts	Os	Ms			Ls		Gs				Ds	
Sidewalk	Qa	Fa	Wa		Oa	Ma										
Seeding	Qe	Fe	We			Me							Ce	Ue		
Sodding	Qo	Fo	Wo			Mo							Co	Uo		
Fence	Qn	Fn	Wn								Gn					
Guardrail	Qu	Fu	Wu	Tu		Mu				Su			Cu			
Asphalt - Friction	Qf	Ff	Wf	Tf	Of	Mf			Lf		Gf				Df	
Stripping	Qp	Fp	Wp	Tp												
RPM's	Qr	Fr	Wr	Tr												

NOTES:
CDIFs- Contract Duration Influence Factors, [shaded] : Not appliable
*- Special Items include fabricated structural members, electro mechanical devices, etc.

Rule 2:

    IF
        The module of estimating contract duration is
         PET
  and Project location is Urban
  THEN
        [Fl] IS GIVEN THE VALUE 1.10
  ELSE
        [Fl] IS GIVEN THE VALUE 0.90

Integration of the Developing Modules

After finishing the development of individual module, the entire system was combined by linking these modules together. Three files such as EXCONDD.CFG, EXCONDD.CMD and EXCONDD.OUT, were developed to manage the execution of EXCONDD and the formation of the reports. These files as shown in Appendix D were created by utilizing the DOS Editor.

EXCONDD.CFG, the system configuration file, defines the knowledge base search strategy which in this case is forward chaining. This file also enables the system to display "EXCONDD" on the upper left corner of the screen whenever it is running. EXCONDD.CMD, the system command file, was created to control the execution of the knowledge bases. The command file controls the mechanisms for data input, rule execution, and results displaying. EXCONDD.OUT manages the formation of reports generated by the system. The general architecture of EXCONDD is shown in Figure 6-5.

A total number of 192 rules have been generated for the execution of EXCONDD. These rules were further classified
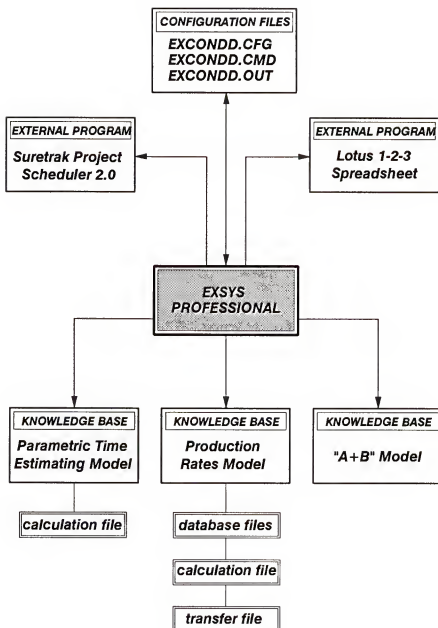
Figure 6-5 General Architecture of EXCONDD

into four categories including the group of general rules, the PTE module rules, the production rates module rules, and the "A+B" module rules. Three hundred variables including numeric and string variables also have been created in this KBES.

Information such as the system subjects, starting text, ending text, qualifiers, variables, and choices is displayed in Appendix E. The system production rules are enclosed in Appendix F. In addition, input and output of various modules in EXCONDD are summarized in Figure 6-6. The implementation flowchart of EXCONDD is also displayed in Figure 6-7.

	Input	Output
PTE Module	▪ Engineer Cost Estimate ▪ Construction Cost Index ▪ Project Characteristics	▪ Project Contract Duration
Production Rates Module	▪ Quantities of Major Work ▪ CD Influence Factors ▪ Major Work Items ▪ Work Durations ▪ Dependencies of Work Items	▪ Graphic Networks ▪ Barchart ▪ Various Reports ▪ Project Contract Duration
"A+B" Module	▪ Total No. of Bids ▪ Daily Road Use Cost ▪ Name of Bidder ▪ Duration Bided ▪ Cost Estimate of Work	▪ Project Total Cost ▪ Project Contract Duration ▪ Name of Successful Bidder

Figure 6-6   Summary of Various Input and Output for EXCONDD
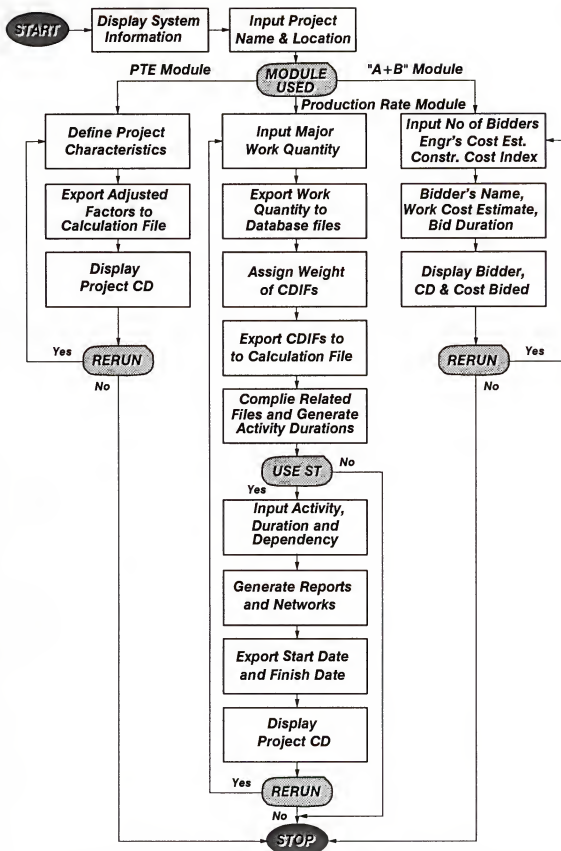
Figure 6-7 The Implementation Procedures of EXCONDD

Summary

The development of various modules in the EXCONDD was addressed in this chapter. This system provides the user with three alternatives for contract duration estimating. The PTE module and the "A+B" module are applicable to any type of projects while the production rates module is limited to highway resurfacing and widening projects. An alternative to the scheduling software utilization is also provided by the system when using the production rates module. In the next chapter the validation of the developing system will be performed utilizing several highway construction projects.

CHAPTER 7
VALIDATION OF THE DEVELOPING SYSTEM

Introduction

After compiling various modules which are embraced in EXCONDD, the next step of KBES development was the system validation. The objective of system validation is to examine the practical application of the developing system. The results of validation are utilized for further refinement of the developing system.

A total number of six projects were used to validate the efficiency of EXCONDD. Four out of the six projects were given by the Florida Department of Transportation (FDOT) engineers while the other two were provided from the attachment of the survey responses by the North Carolina Department of Transportation (NCDOT). The four FDOT projects were utilized in testing the PTE module and Production Rates module while the projects obtained from NCDOT were employed for the validation of the "A+B" module.

In each case study, information necessary for each project is provided. Following that, the result generated by different modules included in EXCONDD is also analyzed. The validation of the developing system is carried out next.

Validating the PTE Module

The process of running the PTE module involves the input of the engineer's estimating cost, current construction index rate, and project characteristics asked by the system. In addition to working days, contract duration in calendar days can also be obtained by entering the time unit conversion factor which is the ratio of the calendar day to the working day. Two projects are utilized in testing the efficiency of the PTE module.

PTE Module Case Study I

This project involves reconstruction of SR109 in Duval County, Florida. This project was provided by a FDOT scheduling engineer who actually established this project's contract duration. The length of the project is about four miles. Other project information provided by the scheduling engineer is listed as follows:

```
Project Description: SR109 Reconstruction Project
Project Location: Duval County, Florida
Engineer Estimate Cost: $950,000
Time Unit Conversion Factor: 1.46
Project Characteristics:
     Contract Type: Reconstruction
     Number of Major Structures: 0
     Traffic Handling: Moderate to Major
     Terrain: Flat
     Location: Rural to Urban Area
     Special Considerations: All Simple Items
     Other Factors: None
```

Based on the information shown above, a 166 calendar days contract duration was generated by the developing PTE module in EXCONDD. Compared to the engineer's estimated time which was 150 calendar days, the contract duration generated by the PTE module is 10.67% more. The result generated by the PTE module is displayed in Figure 7-1.

```
############################################################
#                    OUTPUT OF EXCONDD                     #
############################################################

Name of the project = SR109 Reconstruction Project
Location of the project = Duval County, Florida
The contract duration estimated using the PTE module in
calendar day: 166
The contract duration estimated using the PTE module in
working day: 114

Adjusted factor for project type = .9
Adjusted factor for the total number of major structures for
the project = .9
Adjusted factor for the traffic impact on the project = 1.08
Adjusted factor for project location = 1.03
Adjusted factor for project terrain = .95
Adjusted factor for project's special considerations = .9
Summation of various adjusted factor values = 5.76
Total no. of factors = 6
```

Figure 7-1 Case Study I Output Generated by the PTE Module

PTE Module Case Study II

The project utilized for case study II was the widening of the existing pavement of SR24 (State Road 24) in Levy County, Florida. This project is about five miles long. Related information of the project is outlined as follows:

```
Project Description: SR24 Widening Project
Project Location: Levy County, Florida
Engineer Estimate Cost: $2,360,000
Time Unit Conversion Factor: 1.46
Project Characteristics:
     Contract Type: Overlay & Widening
     Number of Major Structures: 0
     Traffic Handling: Moderate
     Terrain: Rolling
     Location: Rural
     Special Considerations: Some Unusual Items
     Other Factors: None
```

According to the above data, the PTE module generated a 184 calendar days contract duration. Compared to the engineer estimate contract duration which was 250 calendar days, the contract duration generated by the module is 26.4% less. The results generated by the PTE module are shown in Figure 7-2.

```
############################################################
#                  OUTPUT OF EXCONDD                       #
############################################################

Name of the project = SR24 Widening Project
Location of the project = Levy County, Florida
The contract duration estimated using the PTE module in
calendar day: 184
The contract duration estimated using the PTE module in
working day: 126

Adjusted factor for project type = .8
Adjusted factor for the total number of major structures for
the project = .9
Adjusted factor for the traffic impact on the project = 1
Adjusted factor for project location = .9
Adjusted factor for project terrain = 1
Adjusted factor for project's special considerations = 1.1
Summation of various adjusted factor values = 5.7
Total no. of factors = 6
```

Figure 7-2 Case Study II Output Generated by the PTE Module

Validating the Production Rates Module

Compared to the PTE module, the production rates module requires much more information for the estimating of contract duration. The information which must provide by the system end user to run the Production Rates module includes project general information, quantity of major work, and allocation of various contract duration influence factors.

After obtaining the major work duration, the system end user has to further define the relationships among the major work items. Various lead time should also be assigned regarding the dependencies of these work items. Suretrak, the EXCONDD default scheduling software, is then utilized to schedule the project and calculate the contract durations of the project.

Two projects provided by different schedulers were used for the test of the Production Rates module. The following sections present the validation of this module.

Production Rates Module Case Study I

A four and one-half miles long highway widening project was chosen as the production rates module case study I. This project is located in Columbia County, Florida. There are 12 major work items involved in the project according to the data given by the FDOT scheduling engineer. Fifteen calendar days were assigned for the mobilization of the project. Other project related information is listed as follows.

Project Description: SR47 Widening Project
Project Location: Columbia County, Florida
Time Unit Conversion Factor: 1.46
Quantities of Major Work Items:
    Clearing/Grubbing: 8.575 acre
    Excavation (Regular): 13492 cy
    Concrete Endwall: 13 cy
    Drainage Structure: 68 lf
    Base widening: 59882 sy
    Asphalt Structure: 8952 ton
    Guardrail: 2175 lf
    Seeding: 29620 sy
    Sodding: 8782 sy
    Asphalt Friction: 4034 ton
    Stripping: 4.5 mile
    RPM: 938 each

After entering the required information into the computer, a hardcopy of work items along with their durations was produced by the system. As shown in Table 7-1, various dependencies of the work were then determined based on the data provided by the scheduling engineer. Table 7-2 shows the allocation of various contract duration influence factors.

Table 7-1   Work Dependency of the Production Rates Module
            Case Study I

ACT #	ACTIVITY DESCRIPTION	DURATION (Work Day)	ACTIVITY DEPENDENCY	DEPENDENCY TYPE
1	Mobilization		–	
2	Clearing\Grubbing		1	
3	Excavation (Regular)		2	
4	Concrete Endwall		3	SS=0
5	Drainage Structure		3	
6	Base Construction		3	SS=7
7	Asphalt-Structural		6	
8	Guardrail		7	
9	Seeding		8	
10	Sodding		9	
11	Asphalt-Friction		8	
12	Stripping		10,11	
13	RPM's		12	

Table 7-2 Allocation of Significant Influence Factors for the Production Rates Module
Case Study I

WORK ITEMS	Weather Impact	Traffic Flow	Project Location	Material Delivery	Night Work	Various Permits	Letting Time	Special Items*	Legal Aspects	Waiting & Delay Time	Conflictin Operation	Utilities Relocation	Dominant Proj. Type	Environment Concerns
Clearing & Grubbing														
Excavation (Regular)														
Excavation (Borrow)														
Concrete Structure														
Concrete Endwall														
Drainage														
Stabilization Roadbed														
Curb/Gutter														
Base Construction	0.90													
Milling Exist Pavemen														
Asphalt - Structural	0.90		0.95											
Sidewalk														
Seeding														
Sodding														
Fence														
Guardrail														
Asphalt - Friction	0.95		0.95											
Stripping														
RPM's														

NOTES:
*- Special Items include fabricated structural members, electro mechanical devices, etc.
(shaded) Not Appliable

According to the reports generated by EXCONDD, a contract duration of 109 in calendar days is assigned for the project as shown in Figure 7-3. The duration estimated by the system is 19.3% shorter than the engineer estimated contract duration which is 135 calendar days. A barchart, as shown in Figure 7-4, is generated by the system to provide a better picture of the project scheduling.

```
############################################################
#                    OUTPUT OF EXCONDD                     #
############################################################

Name of the project = SR47 Winding Project
Location of the project = Columbia County, Florida
The contract duration estimated using the production rate
module in calendar day: 109

The combined effect of various factors on base construction
 = .9
The combined effect of various factors on asphalt-structural
 = .855
The combined effect of various factors on asphalt-friction
 = .903
```

Figure 7-3   Case Study I Output Generated by
the Production Rates Module
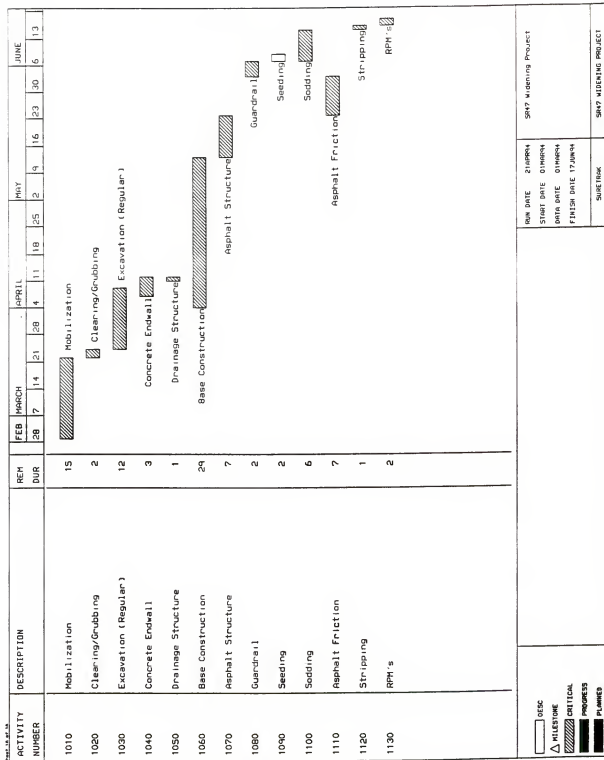
Figure 7-4 Suretrak Generated Barchart for the Production Rates Module Case Study I

Production Rates Module Case Study II

The production rate module case study II used a highway widening project located in Hillsbobough County, Florida. This project was provided by the scheduling engineer in FDOT district seven. Twelve working days was determined for the project mobilization. General information of the project is listed below. The dependencies of these involving work items are provided in Table 7-3. The allocation of various contract duration influence factors was summarized in Table 7-4.

```
Project Description: SR574 Widening Project
Project Location: Hillsborough County, Florida
Quantities of Major Work Items:
     Clearing/Grubbing: 5.93 acre
     Excavation (Regular): 4868 cy
     Excavation (Borrow): 2315 cy
     Stabilization Roadbed: 2352 sy
     Storm Drainage: 144 lf
     Base widening: 13018 cy
     Milling Existing Pavement: 13833 sy
     Asphalt Structure: 4317 tn
     Asphalt Friction: 2128 tn
     Curb/Gutter: 470 lf
     Sodding: 2843 sy
     Seeding: 13894 sy
     Stripping: 5.5 mile
     RPM: 519 each
```

Table 7-3   Work Dependency of the Production Rates Module
             Case Study II

ACT #	ACTIVITY DESCRIPTION	DURATION (Work Day)	ACTIVITY DEPENDENCY	DEPENDENCY TYPE
1	Mobilization		–	
2	Clearing\Grubbing		1	
3	Excavation (Regular)		2	
4	Excavation (Borrow)		3	SS=5
5	Stabilization Roadbed		4	
6	Drainage		4	
7	Base Construction		4	
8	Milling Exist Pvt.		7	
9	Asphalt-Structural		4	
10	Asphalt-Friction		8,9	
11	Curb/Gutter		7	
12	Seeding		10	
13	Sodding		10	
14	Stripping		12,13	
15	RPM's		14	

Table 7-4 Allocation of Significant Influence Factors for the Production Rates Module Case Study II

WORK ITEMS \ CDIFs	Weather Impact	Traffic Flow	Project Location	Material Delivery	Night Work	Various Permits	Letting Time	Special Items*	Legal Aspects	Waiting & Delay Time	Conflictin Operation	Utilities Relocation	Dominant Proj. Type	Environment Concerns
Clearing & Grubbing														
Excavation (Regular)														
Excavation (Borrow)														
Concrete Structure														
Concrete Endwall														
Drainage														
Stabilization Roadbed		0.95												
Curb/Gutter		0.90												
Base Construction														
Milling Exist Pavemen														
Asphalt - Structural		0.72												
Sidewalk														
Seeding														
Sodding														
Fence														
Guardrail														
Asphalt - Friction		0.72												
Stripping														
RPM's														

NOTES:
*- Special Items include fabricated structural members, electro mechanical devices, etc.
▓ Not Appliable

After obtained the major work durations, the end user then can go further to schedule the project utilizing either the Suretrak Project Scheduler or other prefer scheduling software. The production rates module generates a contract duration of 77 calendar days which is 9.41% shorter than the engineer's estimated duration which was 85 calendar days. The output generates by the production rates module is also shown in Figure 7-5, and Figure 7-6 respectively.

```
###########################################################
#                  OUTPUT OF EXCONDD                      #
###########################################################

Name of the project = SR574 Winding Project
Location of the project = Hillsborough County, Florida
The contract duration estimated using the production rate
module in calendar day: 77

The combined effect of various factors on stabilization
roadbed = .95
The combined effect of various factors on base construction
 = .9
The combined effect of various factors on milling exist
pavement = .9
The combined effect of various factors on asphalt-structural
 = .72
The combined effect of various factors on asphalt-friction
 = .72
```

Figure 7-5   Case Study II Output Generated by
the Production Rates Module
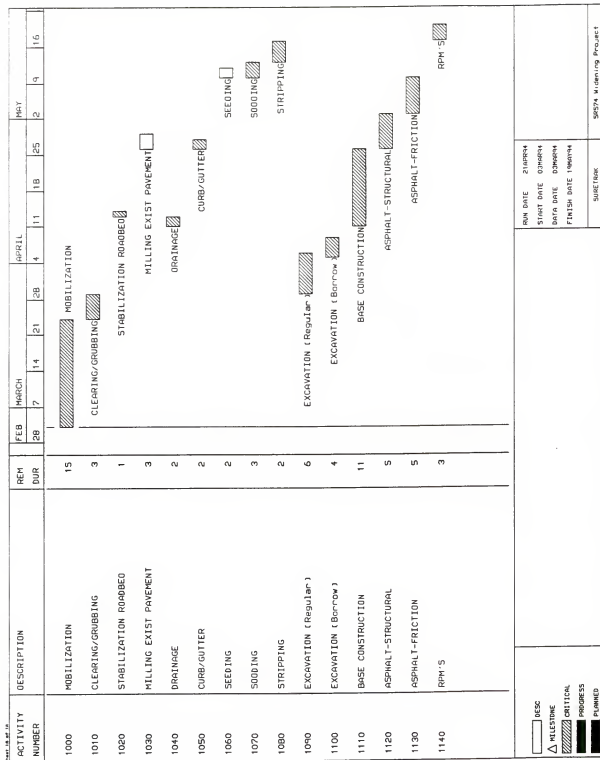
Figure 7-6   Suretrak Generated Barchart for the Production Rates Module Case Study II

ACTIVITY NUMBER	DESCRIPTION	REM DUR
1000	MOBILIZATION	15
1010	CLEARING/GRUBBING	3
1020	STABILIZATION ROADBED	1
1030	MILLING EXIST PAVEMENT	3
1040	DRAINAGE	2
1050	CURB/GUTTER	2
1060	SEEDING	2
1070	SODDING	3
1080	STRIPPING	2
1090	EXCAVATION (Regular)	6
1100	EXCAVATION (Borrow)	4
1110	BASE CONSTRUCTION	11
1120	ASPHALT-STRUCTURAL	5
1130	ASPHALT-FRICTION	5
1140	RPM'S	3

Validating the "A+B" Module

Similar to the other modules, the "A+B" module is tested by utilizing two real highway projects. To use this module to estimate contract duration, the user has to provide various information such as project name, project location, bidder names, bid work costs, and bid durations.

After entering various required information, the project contract duration will be generated by EXCONDD based on the "A+B" method. The validation of the "A+B" module is presented as follows.

"A+B" Module Case Study I

Case study I involved a reconstruction and widening project located at I-85 near Charlotte, North Carolina. The engineer estimated contract duration is 762 days. A $7,000 Daily Road User Cost was also determined for the project. Relevant bid information is listed in Table 7-5.

Table 7-5 Bids Tabulation for I-85 Project

Contractor	Work Cost Bid ($)	Duration Bid (Days)
A	19,518,537.20	672
B	19,734,919.36	702
C	20,198,158.30	642
D	19,371,550.54	762
E	21,138,086.98	762

According to the results generated by EXCONDD, Contractor A was the low bidder with a project contract duration of 672 calendar days. A savings of 90 days (762-672) or $630,000 (90 x $7,000) was achieved using the "A+B" method. The output generated by the "A+B" module is also displayed in Figure 7-7.

```
###############################################################
#                    OUTPUT OF EXCONDD                        #
###############################################################
Name of the project = I-85 Widening Project
Location of the project = Charlotte, North Carolina
The contract duration estimated using the "A+B" module in
working day: 672

Name of the successful bidder = AA
Project final bid price = 19,518,537.20
```

Figure 7-7 Case Study I Output Generated by the "A+B" Module

"A+B" Module Case Study II

This project involves the extension of an acceleration lane at the I-77 interchange with the I-40 in Iredell County, North Carolina. In addition to improving the ramp, the contractor needed to widen the I-77 eastbound bridge over I-40 and rehabilitate the bridge deck. The Daily Road User Cost was determined to be $2000/day. So was the daily Liquidated Damages. The engineer estimated contract duration is 636 days. Other bid information is summarized in Table 7-6.

Table 7-6   Bids Tabulation for I-77 Project

Contractor	Work Cost Bid ($)	Duration Bid (Days)
A	1,288,332.89	240
B	1,431,339.84	352
C	1,403,984.67	450
D	1,348,811.81	500
E	1,125,387.03	352

Contractor A, based on the results of EXCONDD, is awarded the project with a contract duration of 240 days. As a result of award of the project to the contractor, a savings of 396 days (636-240) or $792,000 (396 x $2,000) was achieved by employing the "A+B" method.   The results obtained from the "A+B" module are shown in Figure 7-8.

```
#############################################################
#                    OUTPUT OF EXCONDD                      #
#############################################################

Name of the project = I-77 Lane Extension Project
Location of the project = Iredell County, North Carolina
The contract duration estimated using the "A+B" module in
working day: 240

Name of the successful bidder = A
Project final bid price = 1,288,332.89
```

Figure 7-8 Case Study II Output Produced by the "A+B" Module

Summary

In this chapter, each module included in EXCONDD was tested using two real projects respectively. The result of the case study is summarized in Table 7-7. Analyzing Table 7-7 concludes that most contract durations generated by EXCONDD are shorter than the contract durations estimated by owners excluding the "A+B" module. For the production rates module, a 10% and 20% shorter contract durations are achieved.

Table 7-7 Summary of Results of System Validation

Module (1)	Case Study No. (2)	Durations Generated by EXCONDD (3)	Durations Estimated by Engineer (4)	Difference in % (5)
PTE	I	166	150	10.67%
	II	184	250	-26.40%
Production Rates	I	109	135	-19.25%
	II	77	85	-9.46%
"A+B"	I	672	672[a]	0.00%
	II	240	240[a]	0.00%

[a]Contract duration estimated by the successful bidder.

Based on the information gathered during the structured interviews, it is impossible to obtain an identical contract duration for a project which is estimated by different schedulers. A 20% difference between contract durations

estimated by different scheduling is considered acceptable. Therefore, it should be noted that contract durations set by different modules of the system do not necessarily have to be the same, however, within acceptable limits they should agree with each other. According to the case study results, it is concluded that the contract durations generated by EXCONDD are acceptable.

SUMMARY AND CONCLUSIONS

Research Objectives

This research focused on developing a systematic approach that can assist the scheduler engineers, project owners, and contractors to determine reasonable contract durations for highway construction projects. In addition, the systematic approach also serves as a basis that can be utilized by future researches for developing other models for different types of construction projects.

Summary

The objectives of the research were accomplished by the development of a KBES entitled EXCONDD. The development of the EXCONDD began with a phase of literature review of the background and current practices of contract duration determination for highway construction. This was followed by another phase of the identification of various contract duration determination influence factors. A nationwide survey was conducted for the investigation of previous two phases. Domain knowledge was collected from identified experts and was converted to fit selected KBES shell, the EXSYS Professional.

Development of various modules for contract duration determination followed in the next phase. The research work also included the validation of the developed KBES using analysis of several real projects.

Three different commercial software packages were used for the development of EXCONDD. EXSYS Professional, which is the control center of the system, integrates several Lotus 123 spreadsheet files and Suretrak Project Scheduler 2.0 scheduling software. EXCONDD is operated on a personal computer in the MS DOS environment. Considering the variety of methods used for contract duration determination, EXCONDD combines three commonly used modules, namely the PTE module, the Production Rates module, and the "A+B" module.

The PTE module uses very limited information to determine project contract duration. The accuracy of this module is less than the accuracy of other modules. However, it does provide an option for a quick estimate of contract duration. This module can be used in small projects and serves best for checking the contract durations estimated using other methods.

With the increasing importance of time value, bidding on time/cost contracting has emerged as one of the most promising approaches for the near future. The "A+B" module is created to enable the system end user to deal with this innovative contracting system. The current module is able to handle information for up to 10 bidders. However, it can be easily expanded to manage more bidders.

Through the evaluation of specific influence factors affecting contract duration, the Production Rates module provides a high accuracy approach for contract duration estimation. The evaluation of the impact of various contract duration influence factors enables the scheduling engineer to examine project parameters in-depth. The main strength of the module is not the estimation of project contract duration but the durations of major work items. With the variety of work dependencies, durations of these major work items perform as an important base for determining project contract duration.

Conclusions

From the investigation conducted during this research several conclusions drawn from this research are:

1) There is no single approach that fits all types of highway projects because of the variety of these projects. However, the more complicated a project is, the more sophisticated the approach should be.

2) The factors affecting contract duration determination vary from project to project. Including all factors in a system is not practical, however, common significant factors can be identified.

3) There is no clear definition of "reasonable contract duration." However, a contract duration that agrees to both project owner and contractor can be seen as a reasonable contract duration.

4) It should be noted that a reasonable contract duration is not necessarily an optimal or shortest contract duration.

5) Various relationships between major work items, such as dependencies and lead times, have significant impact on the length of contract duration.

The approach developed in this research is offered as the basic form that can be used by researchers as a prototype to develop models for other types of construction projects. The results obtained through the development of this research would provide the scheduler engineers, project owners, and contractors an alternative for contract duration estimation, and thereby help to obtain reasonable contract durations for highway construction projects.

Finally, it should be noted that even though the data used for this study was from highway construction projects, the concept developed can also be applied to other types of construction, such as building construction and industrial construction with minimum modifications. Although the contract duration influencing factors will be different due to the unique nature of each category of construction projects, the principles of the concept remains the same.

Future Refinement of the Developed System

Developing a non-restriction full scale system is always the primary goal for a system developer during the original development phase. The job usually can not be accomplished due to the limitations of time and resource. However, efforts can be made later to upgrade the developing system.

There are a few handicaps existing in the current phase of EXCONDD. For example, the external databases of the Production Rates module contain only the daily production rates which are applicable only in the state of Florida. As a result, this module can only be utilized for widening and resurfacing project contract duration estimation in Florida. There are several things that can be done to refine EXCONDD and thereby enlarge its capabilities. The most important ones are discussed next.

Expanding the Production Rates Module

As mentioned before, the Production Rates module included in EXCONDD is aimed towards highway construction widening and resurfacing projects in Florida. This module can be expanded to other types of projects such as reconstruction and new roadway. In order to achieve this, expansion various production rates and work procedures of different type of projects should be gathered and classified. Various databases of these work production rates ought to be built, installed, and attached to EXCONDD.

Expanding the System Knowledge Base

In its current phase, EXCONDD requires direct data (weight of the influence factors) input by the system end user. To upgrade EXCONDD to a fully developed system, it is recommended that the user should be given the option of extracting the weight of influence factors from a database. An influence factors database would certainly be a useful supplement to the existing knowledge base. To achieve this, extensive efforts need to be made because the process involves quantifying qualitative influence factors for different types of projects.

Creating a User Interface Program

EXCONDD, at this point, utilizes a defined set of widening project work items in the Production Rates module. The user is expected to enter the quantities of defined work items. The system determines the durations of defined work items utilizing its databases. However, to obtain CPM and Barchart, when Suretrak is invoked, the user needs to physically transfer all the relevant work item data such as work item description and computed durations to the scheduling program. Dependencies of work items are defined by the user at the same time. The present arrangement can be improved to reduce both the efforts needed on the part of the user and the possibility of entering incorrect data.

The above described problem can be effectively resolved by including a user interface program in the system. Such a

program will function to transfer the basic work item data from Exsys directly to Suretrak. The user will be able to define dependencies once activities and their durations are listed in the scheduling program. Undoubtedly such a program will increase the efficiency, speed and effectiveness of EXCONDD and at the same time relieve the user from performing additional non-mandatory tasks.

Utilizing the Windows Version EXSYS Shell

During the development of EXCONDD, the system developer encountered various obstacles. The system execution strategy was dominated by the PC Conventional Memory. As a result, inefficiency is created because of the limited Memory of hardware.

For instance, EXSYS is not able to write 20 pieces of data at one time directly to a Lotus 123 spreadsheet file because of the limitation of Conventional Memory. To overcome the problem, the 20-piece data were cut into two 10-piece data sets and sent to different files. Following the completion of exporting the data, the Lotus 123 combine function was used to convert these data into a file.

With the utilization of the Windows version EXSYS Professional shell, this problem can be resolved and will significantly simplify the system's overall structure. As a result, a more effective EXCONDD can be built.

Recommendations for Future Research

During the course of the research for this study, several areas that needed further study were identified. These areas include the followings.

Standardizing the Content of Work Production Rates Database

Based on the data collected during the research study, there are large variations in classification of work items. This situation increases the difficulty of integrating various work items into the system. Therefore, standardizing various work items seems to be an important task need to be completed soon.

Conducting Research on the Impact Measurement of the Contract Duration Influence Factors

At this stage, the measurement of contract duration influence factors on contract duration determination has not been addressed adequately in various publications. However, there is a need to conduct research to investigate and quantify various impacts of these influence factors which can assist in assigning priority of such factors. As a result, it is strongly suggested that more researches in this area should be carried out.

Developing Similar Approach for Other Types of Construction

Similar to the highway construction, other categories of construction such as building construction and industry construction have similar needs of establishing a systematic

approach to determine reasonable contract duration for various projects. Therefore, applying the developed approach as a fundamental basis to develop similar approached for contract duration determination for other types of construction will benefit the construction personnel and the industry.

Finally, it is hoped that this research and the approach developed in this research has provided the construction industry with an analysis and management tool to obtain reasonable contract durations for scheduler engineers, project owners, and contractors. It is also hoped that this research will serve as a basis for the determination of contract durations for other categories of construction.

APPENDIX A
NATIONWIDE QUESTIONNAIRE SURVEY

DETERMINATION OF CONTRACT TIME FOR HIGHWAY CONSTRUCTION PROJECTS

Please have this questionnaire completed by the department, unit, or division responsible for determination of contract time (duration) for highway construction projects. Any background material such as documents or reports will be appreciated and, if requested, will be returned.

RESPONDENT INFORMATION:

Name: _____   Agency: _____

Title:_____   Address:_____

Division or Unit:_____   _____

Phone_____   Date: _____

A.   How does your agency determine contract duration?

☐   production rates
☐   bar charts
☐   Critical Path Method (CPM)
☐   combination method (e.g., production rates and bar chart)
☐   parametric time estimate (e.g., cost-time)
☐   other (please specify) _____

Describe below the method that your agency uses, including any comments regarding the method's advantages, disadvantage, accuracy, etc. (Please send any written data, including procedures, examples, past research, etc.)

NCHRP Project 20-5, TOPIC 24-04   Agency:_____
"Determination of Contract Time for Highway construction Projects"

B. **Does your agency use or consider using any of the "innovative" ideas below for determining contract time?**

☐ bidding on cost and time ("A+B system")
☐ lane rental
☐ completion date
☐ special incentive/disincentive system (please describe)

_____
_____
_____

☐ other ideas from your experience or from others' experiences in the United States or abroad (please describe)?

_____
_____
_____

Comments:

Person completing Part B (if different from Part A):
Name: _____
Phone: _____

NCHRP Project 20-5, TOPIC 24-04   Agency:_____
        "Determination of Contract Time for Highway Construction Projects"

C.   **There are many factors that may affect the determination of contract time. Please check the factors below that your agency considers when determining highway construction project contract time. After each item that you check, please briefly describe the relationship of that factor to the determination of contract time for a project. If you have any published data, please send it or describe it below.**

   Factors (not in order):

☐   weather and seasonal effects -

☐   mobilization and assembly time -

☐   calendar day and/or working days -

☐   special items (e.g., fabricated structural members, electromechanical devices) -

☐   traffic impacts -

☐   type of project -

☐   budget and contract payment concerns -

☐   effect of letting time -

☐   legal aspects -

☐   use of "flex time" -

☐   effect of curves or computer programs on contract time determination -

☐   effect of critical path methods (CPM) -

☐   computer usage -

☐   relocation of utilities for construction -

☐   dominant project type (structures vs. roadway) -

☐   location of the project (urban, rural, metropolitan area) -

☐   material delivery time -

☐   waiting and delay times -

NCHRP Project 20-5, TOPIC 24-04   Agency:_____
  "Determination of Contract Time for Highway construction Projects"

Part C. (continued)

☐   conflicting construction operations -

☐   permits

☐   night work and weekend work -

☐   environmental issues -

☐   others (please specify) -

Comments (use an additional sheet if necessary):

Person completing Part C (if different from Part A):

Name: _____
Phone: _____

NCHRP Project 20-5, TOPIC 24-04   Agency:_____
"Determination of Contract Time for Highway Construction Projects"

D.   We would also like to know contractors' opinions on the subject of determination of contract duration. Will you please identify 1-2 contractors in your state that might be willing to answer a similar questionnaire?

Contractor: _____
Contact person to call: _____
Address: _____
                _____
Phone: _____

Contractor: _____
Contact person to call: _____
Address: _____
                _____
Phone: _____

E.   Please identify other personnel within your agency (but in different divisions, units or departments) who may contribute to highway construction contract time determination.

Name: _____
Division: _____
Phone: _____

Name: _____
Division: _____
Phone: _____

Thank you for your cooperation. Please return the completed questionnaire to:

Dr. Zohar J. Herbsman
University of Florida
Department of Civil Engineering
345 Weil Hall
Gainesville, FL 32611
Phone:(904) 392-0935
FAX:904-392-3394

APPENDIX B
QUESTIONNAIRE OF STRUCTURED INTERVIEWS

QUESTIONNAIRE OF STRUCTURED INTERVIEWS

I. General Questions

1) Describe the relationship between design, specification and setting contract duration.

2) Please describe the procedure of estimating a highway widening project contract duration.

3) Is the same procedure also used for Incentive/Disincentive (I/D) projects ?

4) How do you estimate the contract duration for a project involving bridge and roadway widening ?

5) When establishing contract durations, do you consider only the major work items or all items in the project ?

6) Please verify the major work items of a highway widening project and look for any missing item.

7) Which scheduling technique do you use for contract duration estimating ?

II. Measuring Influence Factors Impact

1) From the factors given in the table, please select all the factors that usually affect contract duration estimation.

2) How do you adjust work production rates responding to project variables such as project types, project sizes, and project location, etc.

3) Do you use Flex Time to allow contractor start the project within a specific window ? If yes, how do you decide the length of the window ?

4) How do you measure the impact of political concerns on project CD in your district ?

6) What is your criteria of rating certain traffic volume as heavy, medium, and light ?

7) How do you adjust work production rates considering different traffic volumes.

8) What is your criteria of allowing night/weekend works.

9) How many night projects currently are awarded or going on in your district ? What about weekend work ?

10) How do you decide work production rates for night time projects ?

11) How do you establish contract durations for nighttime project ?

12) What kind of utilities are usually involved for a widening project in terms of utilities relocation ?

13) What is the Basis of your adding extra time for utilities relocation?

14) How do you account for the weather impact ?

15) How do you decide the amount of time for mobilization ?

16) What kind of environmental issues you commonly consider when estimating contract duration ?

III. FDOT Procedure of Setting a CD

1) Determine major work items

2) Sequence all selected work items

3) Allocate quantities to work items

4) Decide production rates for work items (considering various factors)

5) Calculate working days for all the selected work items

6) Convert activity working days to calendar days

Calendar Days = 1.46^{*} x Working Days

Where
     *: equal to <u>1.209</u> for 6 day/wk project

7) Assign lead time between major works

8) Assign duration for General Time

9) Draw Barchart

10) Round off the obtained duration and determine project contract duration

IV. Major Work Items for Highway Widening Project

Mobilization

Clearing/Grubbing

Excavation (Regular & Borrow)

Concrete Structure

Concrete Endwall

Drainage Structure

Stabilization Roadbed

Curb/Gutter

Base Construction

Milling Exist Pavement

Asphalt-Structural

Seeding

Sodding

Fence

Sidewalk

Guardrail

Asphalt-Friction

Stripping

RPM's (Reflective Pavement Markers)

APPENDIX C
CONTRACT DURATION ESTIMATION USING THE PTE APPROACH

Contract Working Days Estimation Using the PTE Approach

The steps listed below detail the processor estimating contract workdays for a construction project:

1. To obtain the Table Estimate, multiply the current engineer's estimate by the ratio of the 1970 Construction Cost Index to the current construction cost index.

2. Using the Table Estimate, select the base value for workdays from the Contract Workday Table

3. From Attachment 5, select the appropriate adjustment factors for use in the "Workday Equation".

4. The number of workdays are computed using the "Workday Equation".

5. The number of workday computed must be evaluated in relation to the letting date and the number of construction work seasons required to complete the project. Adjust the letting date whenever possible to keep the number of work seasons to a minimum. An average of 180 days per construction season should be used as a basis of analysis.

6. Compare the number of workdays determined in Step 5 to the range of acceptable values in the Contract Workday Table.

7. The above procedure can be superseded to obtain an earlier completion date when a contract end date is required due to extenuating circumstances.

TABLE ESTIMATE

Table Estimate = Current Engineer's Estimate x Cost Index Rate

where Cost Index Rate = 1979 Cost Index/Current Index

CONTRACT WORKDAY TABLE

TABLE ESTIMATE	BASE VALUE	ACCEPTANCE RANGE
Less than $100,000	1[a]	Less than 100
$100,000	100	75-125
$250,000	125	100-150
$500,000	150	120-180
$750,000	200	170-230
$1,000,000	250	215-285
$2,000,000	300	260-340
$3,000,000	350	305-395
$5,000,000	400	350-450
$7,000,000	450	400-500

WORKDAY EQUATION

Workday = 2 x Base Value x (1 + Factors - Number of Factors)

Note: [a]- For project less than $100,000 workdays are assigned by evaluating plan quantities and type of work.

ADJUSTMENT FACTORS FOR PROJECT COMPLEXITY

Contract Type

New Construction	1.00
Reconstruction	0.90
Overlay & Widening	0.80
Overlay	0.70
Safety	0.60

Number of Major Structures

0	0.90
1-2	0.95
3-5	1.00
> 5	1.10

Traffic Handling

Minor	0.90
Minor to Moderate	0.98
Moderate	1.00
Moderate to Major	1.08
Major	1.10

Location

Rural	0.90
Rural to Urban	1.03
Urban	1.10

Terrain

Flat	0.95
Flat to Rolling	0.98
Rolling	1.00
Rolling to Mountainous	1.10
Mountainous	1.15

Special Considerations

Simple Items	0.90
Unusual Items	1.10

Others

Other Concern Items	0.90-1.10

APPENDIX D
CONFIGURATION FILES OF EXCONDD

<u>EXCONDD.CFG</u>

Forward

Maxmem

Noquestions

Nocheck

Round

Screen_Title=EXCONDD

Width=70

No-Password

EXCONDD.CMD

```
IF [module]=1

   :LOOP

   RULES 4-29

   RESULTS1 /C:LOOP /R:excondd.out

ENDIF

IF [module]=2

   :LOOP

   RULES 30-194

   RESULTS2 /C:LOOP /R:excondd.out

ENDIF

IF [module]=3

    :LOOP

    RULES 196-255

    RESULTS3 /C:LOOP /R:excondd.out

ENDIF
```

EXCONDD.OUT

```
FILE C:\EXSYSP\RESULTS /A
"###########################################################"
"#                    OUTPUT OF EXCONDD                    #"
"###########################################################"
 FIRST "   "

 V226

 V227

 C>0

 FIRST "   "

 V2

 V3

 V4

 V5

 V6

 V7

 V8

 V9

 V10

 V162 <> 1

 V163 <> 1

 V164 <> 1

 V165 <> 1

 V166 <> 1

 V167 <> 1

 V168 <> 1
```

```
V169 <> 1

V170 <> 1

V171 <> 1

V172 <> 1

V173 <> 1

V174 <> 1

V175 <> 1

V176 <> 1

V177 <> 1

V178 <> 1

V179 <> 1

V180 <> 1

V225

V224/,

FIRST "   "

BEEP

CLOSE

DISPLAY c:\exsysp\RESULTS

FIRST "   "
```

APPENDIX E
PROGRAM INTRODUCTION, QUALIFIERS, CHOICES, AND VARIABLES

<u>PROGRAM INTRODUCTION</u>

Subject:
A Knowledge-Based Expert System to Estimated Contract
Durations for Highway Constructions

Author:
By WEI-TONG CHEN

Starting text:
This system enable the users to estimate contract duration for
highway construction projects. Three modules, the Parametric
Time Estimating (PTE), the Production Rates and the "A+B", are
contained in the system. The Production Rates module is
limited to widening and resurfacing projects while the others
have no restriction of project application. By entering
relative data asked, the project contract duration can be
determined and displayed.

Ending text:
It should be recognized that contract durations estimated by
different modules contained in the system are not necessarily
identical. However, they should AGREEABLE each other. Only
the solutions to the utilized module will be displayed on the
next screen.

Uses all applicable rules in data derivations.

Probability System: Custom formulas

INITIAL CHOICE CONFIDENCE: 0.000000

DISPLAY THRESHOLD: 1

<u>LIST OF QUALIFIERS</u>

QUALIFIERS:

1 To estimate contract duration, the module used is

the Parametric Time Estimating module
the Production Rates module
the "A+B" module

2 The type of project is

New Construction
Reconstruction
Overlay & Widening
Overlay
Safety

Display at end

3 The number of total major structures in the project is

0
1-2
3-5
>5

Display at end

4 The traffic impact on the project is

Minor
Minor to Moderate
Moderate
Moderate to Major
Major

Display at end

5 The project location is

in Rural Areas
in Rural-Urban Areas
in Urban Areas

Display at end

6 The terrain of the project is

Flat
Flat to Rolling
Rolling
Rolling to Mountainous
Mountainous

Display at end

7 In the project, there are

All Simple Items
Some Unusual Items

8 There are

other items need to be concerned
no other item needs to be concerned

9 The time unit(s) used to measure the project contract
duration is

Working Day
Calendar Day
Both

10 Major work items involved with the project include

Clearing & Grubbing
Excavation (Regular)
Excavation (Borrow)
Concrete Structure
Concrete Endwall
Drainage
Stabilization Roadbed
Curb/Gutter
Base Construction
Milling Exist Pavement
Asphalt-Structural
Sidewalk
Seeding
Sodding
Fence
Guardrail
Asphalt-Friction
Stripping
RPM's

11 The factors affecting the production rates of Clearing &
Grubbing include

Weather Impact
Project Location
Night Work
Various Permits
Legal Aspects
Conflicting Operation
Utilities Relocation
Environment Concerns
Other Unmentioned Factors
None of Above

12 The factors affecting the production rate of Excavation
(Regular) include

Weather Impact
Project Location
Night Work
Various Permits
Utilities Relocation
Dominant Project Type
Environment Concerns
Other Unmentioned Factors
None of Above

13 The factors affecting the production rate of Excavation
(borrow) include

Weather Impact
Project Location
Night Work
Various Permits
Utilities Relocation
Dominant Project Type
Environment Concerns
Other Unmentioned Factors
None of Above

14 The factors affecting the production rate of Concrete
Structure include

Weather Impact
Traffic Flow
Project Location
Material Delivery
Night Work
Letting Time

Special Items
Utilities Relocation
Environment Concerns
Other Unmentioned Factors
None of Above

15 The factors affecting the production rate of concrete
endwall include

Weather Impact
Traffic Flow
Project Location
Material Delivery
Night Work
Various Permits
Utilities Relocation
Environment Concerns
Other Unmentioned Factors
None of Above

16 The factors affecting the production rate of drainage
include

Weather Impact
Traffic Flow
Project Location
Material Delivery
Night Work
Various Permits
Special Items
Operation Conflicting
Utilities Relocation
Environment Concerns
Other Unmentioned Factors
None of Above

17 The factors affecting the production rate of stabilization
roadbed include

Weather Impact
Traffic Flow
Project Location
Utilities Relocation
Environment Concerns
Other Unmentioned Factors
None of Above

18 The factors affecting the production rate of curb/gutter include

Weather Impact
Material Delivery
Night Work
Waiting & Delay Time
Utilities Relocation
Other Unmentioned Factors
None of Above

19 The factors affecting the production rate of base construction include

Weather Impact
Traffic Flow
Project Location
Utilities Relocation
Environment Concerns
Other Unmentioned Factors
None of Above

20 The factors affecting the production rate of milling exist pavement include

Weather Impact
Traffic Flow
Project Location
Dominant Project Type
Other Unmentioned Factors
None of Above

21 The factors affecting the production rate of asphalt-structural include

Weather Impact
Traffic Flow
Project Location
Material Delivery
Project Letting Time
Legal Aspects
Dominant Project Type
Other Unmentioned Factors
None of Above

22 The factors affecting the production rate of sidewalk include

Weather Impact
Project Location
Material Delivery
Night Work
Utilities Relocation
Other Unmentioned Factors
None of Above

23 The factors affecting the production rate of seeding include

Weather Impact
Material Delivery
Operation Conflicting
Utilities Relocation
Other Unmentioned Factors
None of Above

24 The factors affecting the production rate of sodding include

Weather Impact
Material Delivery
Operation Conflicting
Utilities Relocation
Other Unmentioned Factors
None of Above

25 The factors affecting the production rate of fence include

Weather Impact
Material Delivery
Legal Aspects
Other Unmentioned Factors
None of Above

26 The factors affecting the production rate of guardrail include

Weather Impact
Material Delivery
Special Items
Operation Conflicting
Other Unmentioned Factors
None of Above

27 The factors affecting the production rate of asphalt-friction include

Weather Impact
Traffic Flow
Project Location
Material Delivery
Project Letting Time
Legal Aspects
Dominant Project Type
Other Unmentioned Factors
None of Above

28 The factors affecting the production rate of stripping include

Weather Impact
Traffic Flow
Other Unmentioned Factors
None of Above

29 The factors affecting the production rate of RPM's include

Weather Impact
Traffic Flow
Other Unmentioned Factors
None of Above

30 It is

necessary to assign duration for project mobilization
not necessary to assign duration for project mobilization

31 The scheduling software used to estimate contract duration is

Suretrak 2.0
Other software

32 The number of bidders join the bid is

Three
Four
Five
Six
Seven
Eight

Nine
Ten

LIST OF CHOICES

CHOICES:

1 The contract duration estimated using the PTE module in working day

2 The contract duration estimated using the PTE module in calendar day

3 The contract duration estimated using the production rate module in calendar day

4 The contract duration estimated using the "A+B" module in working day

LIST OF VARIABLES

VARIABLES:

1   Module
The module used to estimate contract duration
Numeric variable

2   Fprojtype
Adjusted factor for project type
Numeric variable

3   Fmajorstruct
Adjusted factor for the total number of major structures for the
project
Numeric variable

4   Ftrafficimpact
Adjusted factor for the traffic impact on the project
Numeric variable

5   Fprojlocation
Adjusted factor for project location
Numeric variable

6   Fterrain
Adjusted factor for project terrain
Numeric variable
Displayed at the end of a run

7   Fspecialconcern
Adjusted factor for project's special considerations
Numeric variable

8   Fothers
Adjusted factor for other considerations in addition to the factors
mentioned before
Numeric variable

9   Fsum
Summation of various adjusted factor values
Numeric variable
Displayed at the end of a run

10   Ftotno
Total no of factors
Numeric variable
Displayed at the end of a run

11   Fcwconvert
Conversion factor of calendar days and working days
Numeric variable
Displayed at the end of a run

12   WDPTE
Contract duration measured in working day estimated using PTE module
Numeric variable
Displayed at the end of a run

13   Cee
Engineer's Estimate Cost
Numeric variable
Displayed at the end of a run

14   Icc
Current Construction Cost Index
Numeric variable
Displayed at the end of a run

15   Wc
Weather impact factor for clearing & grubbing
Numeric variable

16   Oc
Project location impact factor for clearing & grubbing
Numeric variable

17   Nc
Night work impact factor for clearing & grubbing
Numeric variable

18   Pc
Permits impact factor for clearing & grubbing
Numeric variable

19   Gc
Legal aspects impact factor for clearing & grubbing
Numeric variable

20   Cc
Operation conflicting impact factor for clearing & grubbing
Numeric variable

21   Uc
Utilities relocation impact factor for clearing & grubbing
Numeric variable

22   Ec
Environment impact factor for clearing & grubbing
Numeric variable

23   Wv
Weather impact factor for regular excavation
Numeric variable

24   Ov
Project location impact factor for regular excavation
Numeric variable

25   Nv
Night work impact factor for regular excavation
Numeric variable

26   Uv
Utilities relocation impact factor for regular excavation
Numeric variable

27   Pv
Permits impact factor for regular excavation
Numeric variable

28   Dv
Dominant project type impact factor for regular excavation
Numeric variable

29   Ev
The production rate adjustment factor due to the environment concerns
impact on excavation (regular)
Numeric variable

30   Ww
Weather impact factor for regular excavation
Numeric variable

31   Ow
Project location impact factor for borrow excavation
Numeric variable

32   Nw
Night work impact factor for borrow excavation
Numeric variable

33   P
Permits impact factor for borrow excavation
Numeric variable

34   Uw
Utilities relocation impact factor for borrow excavation
Numeric variable

35   Dw
Dominant project type impact factor for borrow excavation
Numeric variable

36   Ew
Environment impact factor for borrow excavation
Numeric variable

37   Wy
Weather impact factor for concrete structure
Numeric variable

38   Ty
Traffic impact factor for concrete structure
Numeric variable

39   Oy
Project location impact factor for concrete structure
Numeric variable

40   Ny
Night work impact factor for concrete structure
Numeric variable

41   My
Material delivery impact factor for concrete structure
Numeric variable

42   Ly
Project letting time impact factor for concrete structure
Numeric variable

43   Sy
Special items impact factor for concrete structure
Numeric variable

44   Uy
Utilities relocation impact factor for concrete structure
Numeric variable

45   Ey
Environment impact factor for concrete structure
Numeric variable

46   Wl
Weather impact factor for concrete endwall
Numeric variable

47   Tl
Traffic impact factor for concrete endwall
Numeric variable

48   Ol
Project location impact factor for concrete endwall
Numeric variable

49   Ml
Material delivery impact factor for concrete endwall
Numeric variable

50   Nl
Night work impact factor for concrete endwall
Numeric variable

51   Pl
Permits impact for concrete endwall
Numeric variable

52   Ul
Utilities relocation impact factor for concrete endwall
Numeric variable

53   El
Environment impact factor for concrete endwall
Numeric variable

54   Wd
Weather impact factor for drainage
Numeric variable

55   Td
Traffic flow impact factor for drainage
Numeric variable

56   Od
Project location impact factor for drainage
Numeric variable

57   Md
Material delivery impact factor for drainage
Numeric variable

58   Nd
Night work impact factor for drainage
Numeric variable

59   Pd
Permits impact factor for drainage
Numeric variable

60   Sd
Special items impact factor for drainage
Numeric variable

61   Xc
Operation conflicting impact factor for drainage
Numeric variable

62   Ud
Utilities relocation impact factor for drainage
Numeric variable

63   Ed
Environment impact factor for drainage
Numeric variable

64   Wg
Weather impact factor for stabilization roadbed
Numeric variable

65   Tg
Traffic flow impact factor for stabilization roadbed
Numeric variable

66   Og
Project location impact factor for stabilization roadbed
Numeric variable

67   Ug
Utilities relocation impact factor for stabilization roadbed
Numeric variable

68   Eg
Environment impact factor for stabilization roadbed
Numeric variable

69   Mt
Material delivery impact factor for curb/gutter
Numeric variable

70   Wt
Weather impact factor for curb/gutter
Numeric variable

71   Nt
Night work impact factor for curb/gutter
Numeric variable

72   At
Waiting & delay time impact factor for curb/gutter
Numeric variable

73   Ut
The production rate adjustment factor due to the utilities relocation
impact on curb/gutter
Numeric variable

74   Wb
Weather impact factor for base construction
Numeric variable

75   Tb
Traffic impact factor for base construction
Numeric variable

76   Ob
Project location impact factor for base construction
Numeric variable

77   Ub
Utilities relocation impact factor for base construction
Numeric variable

78 Eb
Environment impact factor for base construction
Numeric variable

79 Wm
Weather impact factor for milling exist pavement
Numeric variable

80 Tm
Traffic impact factor for milling exist pavement
Numeric variable

81 Om
Project location impact factor for milling exist pavement
Numeric variable

82 Dm
Dominant project type impact factor for milling exist pavement
Numeric variable

83 Ws
Weather impact factor for asphalt-structural
Numeric variable

84 Ts
Traffic impact factor for asphalt-structural
Numeric variable

85 Os
Project location impact factor for asphalt-structural
Numeric variable

86 Ms
Material delivery impact factor for asphalt-structural
Numeric variable

87 Ls
The production rate adjustment factor due to the project
letting time
impact on asphalt-structural
Numeric variable

88   Gs
Legal aspects impact factor for asphalt-structural
Numeric variable

89   Ds
Dominant project type impact factor for asphalt-structural
Numeric variable

90   Wa
Weather impact factor for sidewalk
Numeric variable

91   Oa
Project location impact factor for sidewalk
Numeric variable

92   Ma
Material delivery impact factor for sidewalk
Numeric variable

93   No
Night work impact factor for sidewalk
Numeric variable

94   Ua
Utilities relocation impact factor for sidewalk
Numeric variable

95   We
Weather impact factor for seeding
Numeric variable

96   Me
Material delivery impact factor for seeding
Numeric variable

97   Ce
Operation conflicting impact factor for seeding
Numeric variable

98   Ue
Utilities relocation impact factor for seeding
Numeric variable

99   Wo
Weather impact factor for sodding
Numeric variable

100   Mo
Material delivery impact factor for sodding
Numeric variable

101   Co
Operation conflicting impact factor for sodding
Numeric variable

102   Uo
Utilities relocation impact factor for sodding
Numeric variable

103   Wn
Weather impact factor for fence
Numeric variable

104   Mn
Material delivery impact factor for fence
Numeric variable

105   Gf
Legal aspects impact factor for asphalt-friction
Numeric variable

106   Wu
Weather impact factor for guardrail
Numeric variable

107   Mu
Material delivery impact factor for guardrail
Numeric variable

108   Su
Special items impact factor for guardrail
Numeric variable

109   Cu
Operation conflicting impact factor for guardrail
Numeric variable

110   Wf
Weather impact factor for asphalt-friction
Numeric variable

111   Tf
Traffic impact factor for asphalt-friction
Numeric variable

112   Of
Project location impact factor for asphalt-friction
Numeric variable

113   Mf
Material delivery impact factor for asphalt-friction
Numeric variable

114   Lf
Project letting time impact factor for asphalt-friction
Numeric variable

115   Gn
Legal aspects impact factor for fence
Numeric variable

116   Df
Dominant project type impact factor for asphalt-friction
Numeric variable

117   Wp
Weather impact factor for stripping
Numeric variable

118   Tp
Traffic flow impact factor for stripping
Numeric variable

119   Wr
Weather impact factor for RPM's
Numeric variable

120   Tr
Traffic impact factor for RPM's
Numeric variable

121   Qc
Total quantity of clearing & grubbing in acre
Numeric variable

122   Qv
Total quantity of regular excavation in cy
Numeric variable

123   Qw
Total quantity of borrow excavation in cy
Numeric variable

124   Qy
Total quantity of concrete structure in cy
Numeric variable

125   Ql
Total quantity of concrete endwall in cy
Numeric variable

126   Qd
Total quantity of drainage in lf
Numeric variable

127   Qg
Total quantity of stabilization roadbed in sy
Numeric variable

128   Qt
Total quantity of curb/gutter in lf
Numeric variable

129   Qb
Total quantity of base construction in sy
Numeric variable

130   Qm
Total quantity of milling exist pavement in sy
Numeric variable

131   Qs
Total quantity of asphalt-structural in ton
Numeric variable

132   Qa
Total quantity of sidewalk in sy
Numeric variable

133   Qe
Total quantity of seeding in sy
Numeric variable

134   Qo
Total quantity of sodding in sy
Numeric variable

135   Qn
Total quantity of fence in lf
Numeric variable

136   Qu
Total quantity of guardrail in lf
Numeric variable

137   Qf
Total quantity of asphalt-friction in ton
Numeric variable

138   Qp
Total quantity of stripping in mile
Numeric variable

139   Qr
Total number of RPM's
Numeric variable

140   OTHc
The adjustment factor for unmentioned factors for clearing &
grubbing
Numeric variable

141   OTHv
The production rate adjustment factor due to the impact of
unmentioned
factors on excavation (regular)
Numeric variable

142   OTHw
The production rate adjustment factor due to the impact of
unmentioned
factors on excavation (borrow)
Numeric variable

143   30
Not apply
Numeric variable

144   OTHy
The adjustment factor for unmentioned impact on concrete
structure
Numeric variable

145   OTHl
The adjustment factor for unmentioned impact on concrete
endwall
Numeric variable

146   OTHd
The adjustment factor for unmentioned factors for drainage
Numeric variable

147   OTHg
The adjustment factor for unmentioned impact on stabilization
roadbed
Numeric variable

148   OTHt
The adjustment factor for unmentioned impact on curb/gutter
Numeric variable

149   OTHb
The adjustment factor for unmentioned impact on base
construction
Numeric variable

150   OTHm
The adjustment factor for unmentioned impact on milling exist
pavement
Numeric variable

151   OTHs
The adjustment factor for unmentioned impact on
asphalt-structural
Numeric variable

152   OTHa
The adjustment factor for unmentioned impact on sidewalk
Numeric variable

153   OTHe
The adjustment factor for unmentioned impact on seeding
Numeric variable

154   OTHo
The adjustment factor for unmentioned impact on sodding
Numeric variable

155   OTHn
The adjustment factor for unmentioned impact on fence
Numeric variable

156   103
1
Numeric variable

157   OTHu
The adjustment factor for unmentioned impact on guardrail
Numeric variable

158   OTHf
The   adjustment   factor   for   unmentioned   impact   on
asphalt-friction
Numeric variable

159   OTHp
The adjustment factor for unmentioned impact on stripping
Numeric variable

160   OTHr
The adjustment factor for unmentioned impact on RPM's
Numeric variable

161   z
Total working days for project mobilization
Numeric variable

162   Fc
The combined effect of various factors on clearing & grubbing
Numeric variable
Displayed at the end of a run

163   Fv
The combined effect of various factors on regular excavation
Numeric variable
Displayed at the end of a run

164   Fw
The combined effect of various factors on excavation (borrow)
Numeric variable
Displayed at the end of a run

165   Fy
The combined effect of various factors on concrete structure
Numeric variable
Displayed at the end of a run

166   Fl
The combined effect of various factors on concrete endwall
Numeric variable
Displayed at the end of a run

167   Fd
The combined effect of various factors on drainage
Numeric variable
Displayed at the end of a run

168   Fg
The combined effect of various factors on stabilization
roadbed
Numeric variable
Displayed at the end of a run

169   Ft
The combined effect of various factors on curb/gutter
Numeric variable
Displayed at the end of a run

170   Fb
The combined effect of various factors on base construction
Numeric variable
Displayed at the end of a run

171   Fm
The combined effect of various factors on milling exist
pavement
Numeric variable
Displayed at the end of a run

172   Fs
The combined effect of various factors on asphalt-structural
Numeric variable
Displayed at the end of a run

173   Fa
The combined effect of various factors on sidewalk
Numeric variable
Displayed at the end of a run

174   Fe
The combined effect of various factors on seeding
Numeric variable
Displayed at the end of a run

175   Fo
The combined effect of various factors on sodding
Numeric variable
Displayed at the end of a run

176   Fn
The combined effect of various factors on fence
Numeric variable
Displayed at the end of a run

177   Fu
The combined effect of various factors on guardrail
Numeric variable
Displayed at the end of a run

178   Ff
The combined effect of various factors on asphalt-friction
Numeric variable
Displayed at the end of a run

179   Fp
The combined effect of various factors on stripping
Numeric variable
Displayed at the end of a run

180   Fr
The combined effect of various factors on RPM's
Numeric variable
Displayed at the end of a run

181   170
[Wb]*[Tb]*[Ob]*[Ub]*[Eb]
Numeric variable

182   Name1
Name of bidder #1
String variable

183   WKcost1
Work cost estimated by bidder #1
Numeric variable

184   Dur1
Duration bided by bidder #1
Numeric variable

185   Name2
Name of bidder #2
String variable

186   WKcost2
Work cost estimated by bidder #2
Numeric variable

187   Dur2
Duration bided by bidder #2
Numeric variable

188   Name3
Name of bidder #3
String variable

189   WKcost3
Work cost bided by bidder #3
Numeric variable

190   Dur3
Duration bided by bidder #3
Numeric variable

191   Name4
Name of bidder #4
String variable

192   WKcost4
Work cost bided by bidder #4
Numeric variable

193   Dur4
Duration bided by bidder #4
Numeric variable

194   Name5
Name of bidder #5
String variable

195   WKcost5
Work Cost bided by bidder #5
Numeric variable

196   Dur5
Duration bided by bidder #5
Numeric variable

197   Name6
Name of bidder #6
String variable

198   WKcost6
Work cost bided by bidder #6
Numeric variable

199   Dur6
Duration bided by bidder #6
Numeric variable

200   Name7
Name of bidder #7
String variable

201   WKcost7
Work cost bided by bidder #7
Numeric variable

202   Dur7
Duration bided by bidder #7
Numeric variable

203   Name8
Name of bidder #8
String variable

204   WKcost8
Work cost bided by bidder #8
Numeric variable

205   Dur8
Duration bided by bidder #8
Numeric variable

206   Name9
Name of bidder #9
String variable

207   WKcost9
Work Cost bided by bidder #9
Numeric variable

208   Dur9
Duration bided by bidder #9
Numeric variable

209   Name10
Name of bidder #10
String variable

210   WKcost10
Work cost bided by bidder #10
Numeric variable

211   Dur10
Duration bided by bidder #10
Numeric variable

212   NOBIDER
Number of bidders
Numeric variable
Displayed at the end of a run

213   Druc
Project daily road user cost
Numeric variable
Displayed at the end of a run

214   Tbid1
Total cost bided by bidder #1
Numeric variable

215   Tbid2
Total cost bided by bidder #2
Numeric variable

216   Tbid3
Total cost bided by bidder #3
Numeric variable

217   Tbid4
Total cost bided by bidder #4
Numeric variable

218   Tbid5
Total cost bided by bidder #5
Numeric variable

219   Tbid6
Total cost bided by bidder #6
Numeric variable

220   Tbid7
Total cost bided by bidder #7
Numeric variable

221   Tbid8
Total cost bided by bidder #8
Numeric variable

222   Tbid9
Total cost bided by bidder #9
Numeric variable

223   Tbid10
Total cost bided by bidder #10
Numeric variable

224   Fbid
Project final bid price
Numeric variable
Displayed at the end of a run

225   Fbidname
Name of the successful bidder
String variable
Displayed at the end of a run

226   Nameproj
Name of the project
String variable
Displayed at the end of a run

227   Locationproj
Location of the project
String variable
Displayed at the end of a run

APPENDIX F
KNOWLEDGE BASE RULES

INTRODUCTION OF KNOWLEDGE BASE RULES

The knowledge base of EXCONDD is built based on the information and knowledge obtained during the knowledge extraction stage. Four different knowledge bases are included in the EXCONDD. They are: general knowledge base, the PTE knowledge base, the production rates knowledge, and the "A+B" knowledge base. The operation of EXCONDD depends upon the fully interaction of these knowledge bases.

A total number of 254 rules have been created for EXCONDD. In order to simplify the rule structure, a forward chaining search strategy was selected and incorporated in the system configuration file.

Based on differences in modules, these rules can be classified into four categories: the general rules (Gen), the PTE module rules (PTE), the production rates module rules (PR), and the "A+B" module rules (AB). Rule names are assigned in accordance with the frame of Module-Module Element-Parameter. For example, a rule named PR-WKITM-QTYC stands for a rule regarding the quantity of work item of Clearing & Grubbing which is contained in the production rates module. The knowledge base rules are listed as follows.

GENERAL RULES

```
/*  RULE NUMBER: 1
RULE: GEN-MODULE-PTE
IF:
      To estimate contract duration, the module used is {the
      Parametric Time Estimating module}
THEN:
      [Nameproj] IS GIVEN THE VALUE [NAMEPROJ]
and:  [Locationproj] IS GIVEN THE VALUE [LOCATIONPROJ]
and:  [Module] IS GIVEN THE VALUE 1
and:  X> SS_WR(c:\exsysp\auto123.wk1, a1, [Module])
and:  [Cee] IS GIVEN THE VALUE [CEE]
and:  [Icc] IS GIVEN THE VALUE [ICC]


/*  RULE NUMBER: 2
RULE: GEN-MODULE-PR
IF:
      To estimate contract duration, the module used is {the
      Production Rates module}
THEN:
      [Nameproj] IS GIVEN THE VALUE [NAMEPROJ]
and:  [Locationproj] IS GIVEN THE VALUE [LOCATIONPROJ]
and:  [Module] IS GIVEN THE VALUE 2
and:  X> SS_WR(c:\exsysp\auto123.wk1, a1, [Module])


/*  RULE NUMBER: 3
RULE: GEN-MODULE-AB
IF:
      To estimate contract duration, the module used is {the
      "A+B" module}
THEN:
      [Nameproj] IS GIVEN THE VALUE [NAMEPROJ]
and:  [Locationproj] IS GIVEN THE VALUE [LOCATIONPROJ]
and:  [Module] IS GIVEN THE VALUE 3
```

THE PTE MODULE RULES

```
/*  RULE NUMBER: 4
RULE: PTE-CHAR-PT1
IF:
      The type of project is {New Construction}
THEN:
      [Fprojtype] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 5
RULE: GEN-CHAR-PT2
IF:
      The type of project is {Reconstruction}
THEN:
      [Fprojtype] IS GIVEN THE VALUE 0.9


/*  RULE NUMBER: 6
RULE: GEN-CHAR-PT3
IF:
      The type of project is {Overlay & Widening}
THEN:
      [Fprojtype] IS GIVEN THE VALUE 0.8


/*  RULE NUMBER: 7
RULE: GEN-CHAR-PT4
IF:
      The type of project is {Overlay}
THEN:
      [Fprojtype] IS GIVEN THE VALUE 0.7


/*  RULE NUMBER: 8
RULE: GEN-CHAR-PT5
IF:
      The type of project is {Safety}
THEN:
      [Fprojtype] IS GIVEN THE VALUE 0.6


/*  RULE NUMBER: 9
RULE: PTE-CHAR-STR1
IF:
      The number of total major structures in the project is
      {0}
THEN:
      [Fmajorstruct] IS GIVEN THE VALUE 0.9
```

```
/*  RULE NUMBER: 10
RULE: PTE-CHAR-STR2
IF:
        The number of total major structures in the project is
        {1-2}
THEN:
        [Fmajorstruct] IS GIVEN THE VALUE 0.95


/*  RULE NUMBER: 11
RULE: PTE-CHAR-STR3
IF:
        The number of total major structures in the project is
        {3-5}
THEN:
        [Fmajorstruct] IS GIVEN THE VALUE 1.00


/*  RULE NUMBER: 12
RULE: PTE-CHAR-STR4
IF:
        The number of total major structures in the project is
        {>5}
THEN:
        [Fmajorstruct] IS GIVEN THE VALUE 1.10


/*  RULE NUMBER: 13
RULE: PTE-CHAR-TRF1
IF:
        The traffic impact on the project is {Minor}
THEN:
        [Ftrafficimpact] IS GIVEN THE VALUE 0.9


/*  RULE NUMBER: 14
RULE: PTE-CHAR-TRA2
IF:
        The traffic impact on the project is {Minor to
        Moderate}
THEN:
        [Ftrafficimpact] IS GIVEN THE VALUE 0.98


/*  RULE NUMBER: 15
RULE: PTE-CHAR-TRA3
IF:
        The traffic impact on the project is {Moderate}
THEN:
        [Ftrafficimpact] IS GIVEN THE VALUE 1.00
```

```
/*  RULE NUMBER: 16
RULE: PTE-CHAR-TRA4
IF:
        The traffic impact on the project is {Moderate to
        Major}
THEN:
        [Ftrafficimpact] IS GIVEN THE VALUE 1.08


/*  RULE NUMBER: 17
RULE: PTE-CHAR-TRA5
IF:
        The traffic impact on the project is {Major}
THEN:
        [Ftrafficimpact] IS GIVEN THE VALUE 1.10


/*  RULE NUMBER: 18
RULE: PTE-CHAR-PLO1
IF:
        The project location is {in Rural Areas}
THEN:
        [Fprojlocation] IS GIVEN THE VALUE 0.9


/*  RULE NUMBER: 19
RULE: PTE-CHAR-PLO2
IF:
        The project location is {in Rural-Urban Areas}
THEN:
        [Fprojlocation] IS GIVEN THE VALUE 1.03


/*  RULE NUMBER: 20
RULE: PTE-CHAR-PLO3
IF:
        The project location is {in Urban Areas}
THEN:
        [Fprojlocation] IS GIVEN THE VALUE 1.10


/*  RULE NUMBER: 21
RULE: PTE-CHAR-TRR1
IF:
        The terrain of the project is {Flat}
THEN:
        [Fterrain] IS GIVEN THE VALUE 0.95


/*  RULE NUMBER: 22
RULE: PTE-CHAR-TRR2
IF:
```

```
        The terrain of the project is {Flat to Rolling}
THEN:
        [Fterrain] IS GIVEN THE VALUE 0.98


/*   RULE NUMBER: 23
RULE: PTE-CHAR-TRR3
IF:
        The terrain of the project is {Rolling}
THEN:
        [Fterrain] IS GIVEN THE VALUE 1.00


/*   RULE NUMBER: 24
RULE: PTE-CHAR-TRR4
IF:
        The terrain of the project is {Rolling to Mountainous}
THEN:
        [Fterrain] IS GIVEN THE VALUE 1.12


/*   RULE NUMBER: 25
RULE: PTE-CHAR-TRR5
IF:
        The terrain of the project is {Mountainous}
THEN:
        [Fterrain] IS GIVEN THE VALUE 1.15


/*   RULE NUMBER: 26
RULE: PTE-CHAR-SPE1
IF:
        In the project, there are {All Simple Items}
THEN:
        [Fspecialconcern] IS GIVEN THE VALUE 0.90


/*   RULE NUMBER: 27
RULE: PTE-CHAR-SPE2
IF:
        In the project, there are {Some Unusual Items}
THEN:
        [Fspecialconcern] IS GIVEN THE VALUE 1.10


/*   RULE NUMBER: 28
RULE: PTE-CHAR-OTHERS
IF:
        To estimate contract duration, the module used is {the
        Parametric Time Estimating module}
and:    There are {other items need to be concerned}
THEN:
```

```
        [Fothers] IS GIVEN THE VALUE [FOTHERS]
and:    [Fsum] IS GIVEN THE VALUE [FPROJTYPE] + [FMAJORSTRUCT]
        + [FTRAFFICIMPACT] + [FPROJLOCATION] + [FTERRAIN] +
        [FSPECIALCONCERN] + [FOTHERS]
and:    [Ftotno] IS GIVEN THE VALUE 7
and:    X> SS_WR(c:\exsysp\pte.wk1, m3, [Cee], m7, [Icc], q9,
        [Ftotno], q7, [Fsum])
ELSE:
        [Fothers] IS GIVEN THE VALUE 1
and:    [Fsum] IS GIVEN THE VALUE [FPROJTYPE] + [FMAJORSTRUCT]
        + [FTRAFFICIMPACT] + [FPROJLOCATION] + [FTER RAIN] +
        [FSPECIALCONCERN]
and:    [Ftotno] IS GIVEN THE VALUE 6
and:    X> SS_WR(c:\exsysp\pte.wk1, m3, [Cee], m7, [Icc], q9,
        [Ftotno], q7, [Fsum])
and:    X> SS_RD(c:\exsysp\pte.wk1, q3, [WDpte])


/*  RULE NUMBER: 29
RULE: PTE-TIMEUNIT
IF:
        To estimate contract duration, the module used is {the
        Parametric Time Estimating module}
and:    The time unit used to measure the project contract
        duration is {Working Day}
THEN:
        X> RUN(123 /B)
and:    X> SS_RD(c:\exsysp\pte.wk1, q3, c1)
ELSE:
        X> RUN(123 /B)
and:    X> SS_RD(c:\exsysp\pte.wk1, q3, [WDpte])
and:    [Fcwconvert] IS GIVEN THE VALUE [FCWCONVERT]
and:    > The contract duration estimated using the PTE module
        in working day- Confidence=[WDPTE]
and:    > The contract duration estimated using the PTE module
        in calendar day- Confidence=[FCWCONVERT]*[WDPTE]
```

THE PRODUCTION RATES MODULE RULES

```
/*  RULE NUMBER: 30
RULE: PR-WKITM-QTYC
IF:
        Major work items involved with the project include
        {Clearing & Grubbing}
THEN:
        [Qc] IS GIVEN THE VALUE [QC]
ELSE:
        [Qc] IS GIVEN THE VALUE 0


/*  RULE NUMBER: 31
RULE: PR-WKITM-QTYV
IF:
        Major work items involved with the project include
        {Excavation (Regular)}
THEN:
        [Qv] IS GIVEN THE VALUE [QV]
ELSE:
        [Qv] IS GIVEN THE VALUE 0


/*  RULE NUMBER: 32
RULE: PR-WKITM-QTYW
IF:
        Major work items involved with the project include
        {Excavation (Borrow)}
THEN:
        [Qw] IS GIVEN THE VALUE [QW]
ELSE:
        [Qw] IS GIVEN THE VALUE 0


/*  RULE NUMBER: 33
RULE: PR-WKITM-QTYY
IF:
        Major work items involved with the project include
        {Concrete Structure}
THEN:
        [Qy] IS GIVEN THE VALUE [QY]
ELSE:
        [Qy] IS GIVEN THE VALUE 0


/*  RULE NUMBER: 34
RULE: PR-WKITM-QTYL
IF:
        Major work items involved with the project include
```

```
        {Concrete Endwall}
THEN:
        [Ql] IS GIVEN THE VALUE [QL]
ELSE:
        [Ql] IS GIVEN THE VALUE 0


/*  RULE NUMBER: 35
RULE: PR-WKITM-QTYD
IF:
        Major work items involved with the project include
        {Drainage}
THEN:
        [Qd] IS GIVEN THE VALUE [QD]
ELSE:
        [Qd] IS GIVEN THE VALUE 0


/*  RULE NUMBER: 36
RULE: PR-WKITM-QTYG
IF:
        Major work items involved with the project include
        {Stabilization Roadbed}
THEN:
        [Qg] IS GIVEN THE VALUE [QG]
ELSE:
        [Qg] IS GIVEN THE VALUE 0


/*  RULE NUMBER: 37
RULE: PR-WKITM-QTYT
IF:
        Major work items involved with the project include
        {Curb/Gutter}
THEN:
        [Qt] IS GIVEN THE VALUE [QT]
ELSE:
        [Qt] IS GIVEN THE VALUE 0


/*  RULE NUMBER: 38
RULE: PR-WKITM-QTYB
IF:
        Major work items involved with the project include
        {Base Construction}
THEN:
        [Qb] IS GIVEN THE VALUE [QB]
ELSE:
        [Qb] IS GIVEN THE VALUE 0
```

```
/*  RULE NUMBER: 39
RULE: PR-WKITM-QTYM
IF:
        Major work items involved with the project include
        {Milling Exist Pavement}
THEN:
        [Qm] IS GIVEN THE VALUE [QM]
ELSE:
        [Qm] IS GIVEN THE VALUE 0


/*  RULE NUMBER: 40
RULE: PR-WKITM-QTYS
IF:
        Major work items involved with the project include
        {Asphalt-Structural}
THEN:
        [Qs] IS GIVEN THE VALUE [QS]
ELSE:
        [Qs] IS GIVEN THE VALUE 0


/*  RULE NUMBER: 41
RULE: PR-WKITM-QTYA
IF:
        Major work items involved with the project include
        {Sidewalk}
THEN:
        [Qa] IS GIVEN THE VALUE [QA]
ELSE:
        [Qa] IS GIVEN THE VALUE 0


/*  RULE NUMBER: 42
RULE: PR-WKITM-QTYE
IF:
        Major work items involved with the project include
        {Seeding}
THEN:
        [Qe] IS GIVEN THE VALUE [QE]
ELSE:
        [Qe] IS GIVEN THE VALUE 0


/*  RULE NUMBER: 43
RULE: PR-WKITM-QTYO
IF:
        Major work items involved with the project include
        {Sodding}
THEN:
        [Qo] IS GIVEN THE VALUE [QO]
ELSE:
```

```
      [Qo] IS GIVEN THE VALUE 0


/*   RULE NUMBER: 44
RULE: PR-WKITM-QTYN
IF:
      Major work items involved with the project include
      {Fence}
THEN:
      [Qn] IS GIVEN THE VALUE [QN]
ELSE:
      [Qn] IS GIVEN THE VALUE 0


/*   RULE NUMBER: 45
RULE: PR-WKITM-QTYU
IF:
      Major work items involved with the project include
      {Guardrail}
THEN:
      [Qu] IS GIVEN THE VALUE [QU]
ELSE:
      [Qu] IS GIVEN THE VALUE 0


/*   RULE NUMBER: 46
RULE: PR-WKITM-QTYF
IF:
      Major work items involved with the project include
      {Asphalt-Friction}
THEN:
      [Qf] IS GIVEN THE VALUE [QF]
ELSE:
      [Qf] IS GIVEN THE VALUE 0


/*   RULE NUMBER: 47
RULE: PR-WKITM-QTYP
IF:
      Major work items involved with the project include
      {Stripping}
THEN:
      [Qp] IS GIVEN THE VALUE [QP]
ELSE:
      [Qp] IS GIVEN THE VALUE 0


/*   RULE NUMBER: 48
RULE: PR-WKTIM-QTYR
IF:
      Major work items involved with the project include
      {RPM's}
```

```
THEN:
        [Qr] IS GIVEN THE VALUE [QR]
ELSE:
        [Qr] IS GIVEN THE VALUE 0


/*  RULE NUMBER: 49
RULE: PR-FACT-WI-C
IF:
        Major work items involved with the project include
        {Clearing & Grubbing}
and:    The factors affecting the production rates of Clearing
        & Grubbing include {Weather Impact}
THEN:
        [Wc] IS GIVEN THE VALUE [WC]
ELSE:
        [Wc] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 50
RULE: PR-FACT-PL-C
IF:
        Major work items involved with the project include
        {Clearing & Grubbing}
and:    The factors affecting the production rates of Clearing
        & Grubbing include {Project Location}
THEN:
        [Oc] IS GIVEN THE VALUE [OC]
ELSE:
        [Oc] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 51
RULE: PR-FACT-NW-C
IF:
        Major work items involved with the project include
        {Clearing & Grubbing}
and:    The factors affecting the production rates of Clearing
        & Grubbing include {Ngiht Work}
THEN:
        [Nc] IS GIVEN THE VALUE [NC]
ELSE:
        [Nc] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 52
RULE: PR-FACT-VP-C
IF:
        Major work items involved with the project include
        {Clearing & Grubbing}
and:    The factors affecting the production rates of Clearing
        & Grubbing include {Various Permits}
```

```
THEN:
      [Pc] IS GIVEN THE VALUE [PC]
ELSE:
      [Pc] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 53
RULE: PR-FACT-LA-C
IF:
      Major work items involved with the project include
      {Clearing & Grubbing}
and:  The factors affecting the production rates of Clearing
      & Grubbing include {Legal Aspects}
THEN:
      [Gc] IS GIVEN THE VALUE [GC]
ELSE:
      [Gc] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 54
RULE: PR-FACT-CO-C
IF:
      Major work items involved with the project include
      {Clearing & Grubbing}
and:  The factors affecting the production rates of Clearing
      & Grubbing include {Conflicting Operation}
THEN:
      [Cc] IS GIVEN THE VALUE [CC]
ELSE:
      [Cc] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 55
RULE: PR-FACT-UR-C
IF:
      Major work items involved with the project include
      {Clearing & Grubbing}
and:  The factors affecting the production rates of Clearing
      & Grubbing include {Utilities Relocation}
THEN:
      [Uc] IS GIVEN THE VALUE [UC]
ELSE:
      [Uc] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 56
RULE: PR-FACT-EC-C
IF:
      Major work items involved with the project include
      {Clearing & Grubbing}
and:  The factors affecting the production rates of Clearing
      & Grubbing include {Environment Concerns}
```

```
THEN:
        [Ec] IS GIVEN THE VALUE [EC]
ELSE:
        [Ec] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 57
RULE: PR-FACT-OTHER-C
IF:
        Major work items involved with the project include
        {Clearing & Grubbing}
and:    The factors affecting the production rates of Clearing
        & Grubbing include {Other Unmentioned Factors}
THEN:
        [OTHc] IS GIVEN THE VALUE [OTHC]
ELSE:
        [OTHc] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 58
RULE: PR-FACT-NONE-C
IF:
        Major work items involved with the project include
        {Clearing & Grubbing}
and:    The factors affecting the production rates of Clearing
        & Grubbing include {None of Above}
THEN:
        [Wc] IS GIVEN THE VALUE 1
and:    [Oc] IS GIVEN THE VALUE 1
and:    [Nc] IS GIVEN THE VALUE 1
and:    [Pc] IS GIVEN THE VALUE 1
and:    [Gc] IS GIVEN THE VALUE 1
and:    [Cc] IS GIVEN THE VALUE 1
and:    [Uc] IS GIVEN THE VALUE 1
and:    [Ec] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 59
RULE: PR-FACT-WI-V
IF:
        Major work items involved with the project include
        {Excavation (Regular)}
and:    The factors affecting the production rate of Excavation
        (Regular) include {Weather Imapct}
THEN:
        [Wv] IS GIVEN THE VALUE [WV]
ELSE:
        [Wv] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 60
RULE: PR-FACT-PL-V
```

```
IF:
      Major work items involved with the project include
      {Excavation (Regular)}
and:  The factors affecting the production rate of Excavation
      (Regular) include {Project Location}
THEN:
      [Ov] IS GIVEN THE VALUE [OV]
ELSE:
      [Ov] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 61
RULE: PR-FACT-NW-V
IF:
      Major work items involved with the project include
      {Excavation (Regular)}
and:  The factors affecting the production rate of Excavation
      (Regular) include {Night Work}
THEN:
      [Nv] IS GIVEN THE VALUE [NV]
ELSE:
      [Nv] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 62
RULE: PR-FACT-UR-V
IF:
      Major work items involved with the project include
      {Excavation (Regular)}
and:  The factors affecting the production rate of Excavation
      (Regular) include {Utilities Relocation}
THEN:
      [Uv] IS GIVEN THE VALUE [UV]

ELSE:
      [Uv] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 63
RULE: PR-FACT-VP-V
IF:
      Major work items involved with the project include
      {Excavation (Regular)}
and:  The factors affecting the production rate of Excavation
      (Regular) include {Various Permits}
THEN:
      [Pv] IS GIVEN THE VALUE [PV]
ELSE:
      [Pv] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 64
```

```
RULE: PR-FACT-PT-V
IF:
      Major work items involved with the project include
      {Excavation (Regular)}
and:  The factors affecting the production rate of Excavation
      (Regular) include {Dominant Project Type}
THEN:
      [Dv] IS GIVEN THE VALUE [DV]
ELSE:
      [Dv] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 65
RULE: PR-FACT-EC-V
IF:
      Major work items involved with the project include
      {Excavation (Regular)}
and:  The factors affecting the production rate of Excavation
      (Regular) include {Environment Concerns}
THEN:
      [Ev] IS GIVEN THE VALUE [EV]
ELSE:
      [Ev] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 66
RULE: PR-FACT-OTHER-V
IF:
      Major work items involved with the project include
      {Excavation (Regular)}
and:  The factors affecting the production rate of Excavation
      (Regular) include {Other Unmentioned Factors}
THEN:
      [OTHv] IS GIVEN THE VALUE [OTHV]

ELSE:
      [OTHv] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 67
RULE: PR-FACT-NONE-V
IF:
      Major work items involved with the project include
      {Excavation (Regular)}
and:  The factors affecting the production rate of Excavation
      (Regular) include {None of Above}
THEN:
      [Wv] IS GIVEN THE VALUE 1
and:  [Ov] IS GIVEN THE VALUE 1
and:  [Nv] IS GIVEN THE VALUE 1
and:  [Uv] IS GIVEN THE VALUE 1
and:  [Pv] IS GIVEN THE VALUE 1
```

```
and:     [Dv] IS GIVEN THE VALUE 1
and:     [Ev] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 68
RULE: PR-FACT-WI-W
IF:
        Major work items involved with the project include
        {Excavation (Borrow)}
and:    The factors affecting the production rate of Excavation
        (borrow) include {Weather Impact}
THEN:
        [Ww] IS GIVEN THE VALUE [WW]
ELSE:
        [Ww] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 69
RULE: PR-FACT-PL-W
IF:
        Major work items involved with the project include
        {Excavation (Borrow)}
and:    The factors affecting the production rate of Excavation
        (borrow) include {Project Location}
THEN:
        [Ow] IS GIVEN THE VALUE [OW]
ELSE:
        [Ow] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 70
RULE: PR-FACT-NW-W
IF:
        Major work items involved with the project include
        {Excavation (Borrow)}
and:    The factors affecting the production rate of Excavation
        (borrow) include {Night Work}
THEN:
        [Nw] IS GIVEN THE VALUE [NW]
ELSE:
        [Nw] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 71
RULE: PR-FACT-VP-W
IF:
        Major work items involved with the project include
        {Excavation (Borrow)}
and:    The factors affecting the production rate of Excavation
        (borrow) include {Various Permits}
THEN:
        [Pw] IS GIVEN THE VALUE [PW]
```

ELSE:
        [Pw] IS GIVEN THE VALUE 1

/* RULE NUMBER: 72
RULE: PR-FACT-UR-W
IF:
        Major work items involved with the project include
        {Excavation (Borrow)}
and: The factors affecting the production rate of Excavation
        (borrow) include {Utilities Relocation}
THEN:
        [Uw] IS GIVEN THE VALUE [UW]
ELSE:
        [Uw] IS GIVEN THE VALUE 1

/* RULE NUMBER: 73
RULE: PR-FACT-PT-W
IF:
        Major work items involved with the project include
        {Excavation (Borrow)}
and: The factors affecting the production rate of Excavation
        (borrow) include {Dominant Project Type}
THEN:
        [Dw] IS GIVEN THE VALUE [DW]
ELSE:
        [Dw] IS GIVEN THE VALUE 1

/* RULE NUMBER: 74
RULE: PR-FACT-EC-W
IF:
        Major work items involved with the project include
        {Excavation (Borrow)}
and: The factors affecting the production rate of Excavation
        (borrow) include {Environment Concerns}
THEN:
        [Ew] IS GIVEN THE VALUE [EW]
ELSE:
        [Ew] IS GIVEN THE VALUE 1

/* RULE NUMBER: 75
RULE: PR-FACT-OTHER-W
IF:
        Major work items involved with the project include
        {Excavation (Borrow)}
and: The factors affecting the production rate of Excavation
        (borrow) include {Other Unmentioned Factors}
THEN:
        [OTHw] IS GIVEN THE VALUE [OTHW]

```
ELSE:
        [OTHw] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 76
RULE: PR-FACT-NONE-W
IF:
        Major work items involved with the project include
        {Excavation (Borrow)}
and:    The factors affecting the production rate of Excavation
        (borrow) include {None of Above}
THEN:
        [Ww] IS GIVEN THE VALUE 1
and:    [Ow] IS GIVEN THE VALUE 1
and:    [Nw] IS GIVEN THE VALUE 1
and:    [Pw] IS GIVEN THE VALUE 1
and:    [Uw] IS GIVEN THE VALUE 1
and:    [Dw] IS GIVEN THE VALUE 1
and:    [Ew] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 77
RULE: PR-FACT-WI-Y
IF:
        Major work items involved with the project include
        {Concrete Structure}
and:    The factors affecting the production rate of Concrete
        Structure include {Weather Impact}
THEN:
        [Wy] IS GIVEN THE VALUE [WY]
ELSE:
        [Wy] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 78
RULE: PR-FACT-TF-Y
IF:
        Major work items involved with the project include
        {Concrete Structure}
and:    The factors affecting the production rate of Concrete
        Structure include {Traffic Flow}
THEN:
        [Ty] IS GIVEN THE VALUE [TY]
ELSE:
        [Ty] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 79
RULE: PR-FACT-PL-Y
IF:
        Major work items involved with the project include
        {Concrete Structure}
```

```
and:    The factors affecting the production rate of Concrete
        Structure include {Project Location}
THEN:
        [Oy] IS GIVEN THE VALUE [OY]
ELSE:
        [Oy] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 80
RULE: PR-FACT-NW-Y
IF:
        Major work items involved with the project include
        {Concrete Structure}
and:    The factors affecting the production rate of Concrete
        Structure include {Night Work}
THEN:
        [Ny] IS GIVEN THE VALUE [NY]
ELSE:
        [Ny] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 81
RULE: PR-FACT-MD-Y
IF:
        Major work items involved with the project include
        {Concrete Structure}
and:    The factors affecting the production rate of Concrete
        Structure include {Material Delivery}
THEN:
        [My] IS GIVEN THE VALUE [MY]
ELSE:
        [My] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 82
RULE: PR-FACT-LT-Y
IF:
        Major work items involved with the project include
        {Concrete Structure}
and:    The factors affecting the production rate of Concrete
        Structure include {Letting Time}
THEN:
        [Ly] IS GIVEN THE VALUE [LY]
ELSE:
        [Ly] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 83
RULE: PR-FACT-SI-Y
IF:
        Major work items involved with the project include
        {Concrete Structure}
```

```
and:    The factors affecting the production rate of Concrete
        Structure include {Special Items}
THEN:
        [Sy] IS GIVEN THE VALUE [SY]
ELSE:
        [Sy] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 84
RULE: PR-FACT-UR-Y
IF:
        Major work items involved with the project include
        {Concrete Structure}
and:    The factors affecting the production rate of Concrete
        Structure include {Utilities Relocation}
THEN:
        [Uy] IS GIVEN THE VALUE [UY]
ELSE:
        [Uy] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 85
RULE: PR-FACT-EC-Y
IF:
        Major work items involved with the project include
        {Concrete Structure}
and:    The factors affecting the production rate of Concrete
        Structure include {Environment Concerns}
THEN:
        [Ey] IS GIVEN THE VALUE [EY]
ELSE:
        [Ey] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 86
RULE: PR-FACT-OTHER-Y
IF:
        Major work items involved with the project include
        {Concrete Structure}
and:    The factors affecting the production rate of Concrete
        Structure include {Other Unmentioned Factors}
THEN:
        [OTHy] IS GIVEN THE VALUE [OTHY]
ELSE:
        [OTHy] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 87
RULE: PR-FACT-NONE-Y
IF:
        Major work items involved with the project include
        {Concrete Structure}
```

```
and:    The factors affecting the production rate of Concrete
        Structure include {None of Above}
THEN:
        [Wy] IS GIVEN THE VALUE 1
and:    [Ty] IS GIVEN THE VALUE 1
and:    [Oy] IS GIVEN THE VALUE 1
and:    [Ny] IS GIVEN THE VALUE 1
and:    [My] IS GIVEN THE VALUE 1
and:    [Ly] IS GIVEN THE VALUE 1
and:    [Sy] IS GIVEN THE VALUE 1
and:    [Uy] IS GIVEN THE VALUE 1
and:    [Ey] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 88
RULE: PR-FACT-WI-L
IF:
        Major work items involved with the project include
        {Concrete Endwall}
and:    The factors affecting the production rate of concrete
        endwall include {Weather Impact}
THEN:
        [Wl] IS GIVEN THE VALUE [WL]
ELSE:
        [Wl] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 89
RULE: PR-FACT-TF-L
IF:
        Major work items involved with the project include
        {Concrete Endwall}
and:    The factors affecting the production rate of concrete
        endwall include {Traffic Flow}
THEN:
        [Tl] IS GIVEN THE VALUE [TL]
ELSE:
        [Tl] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 90
RULE: PR-FACT-PL-L
IF:
        Major work items involved with the project include
        {Concrete Endwall}
and:    The factors affecting the production rate of concrete
        endwall include {Project Location}
THEN:
        [Ol] IS GIVEN THE VALUE [OL]
ELSE:
        [Ol] IS GIVEN THE VALUE 1
```

```
/*   RULE NUMBER: 91
RULE: PR-FACT-MD-L
IF:
     Major work items involved with the project include
     {Concrete Endwall}
and: The factors affecting the production rate of concrete
     endwall include {Material Delivery}
THEN:
     [Ml] IS GIVEN THE VALUE [ML]
ELSE:
     [Ml] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 92
RULE: PR-FACT-NW-L
IF:
     Major work items involved with the project include
     {Concrete Endwall}
and: The factors affecting the production rate of concrete
     endwall include {Night Work}
THEN:
     [Nl] IS GIVEN THE VALUE [NL]
ELSE:
     [Nl] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 93
RULE: PR-FACT-VP-L
IF:
     Major work items involved with the project include
     {Concrete Endwall}
and: The factors affecting the production rate of concrete
     endwall include {Various Permits}
THEN:
     [Pl] IS GIVEN THE VALUE [PL]
ELSE:
     [Pl] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 94
RULE: PR-FACT-UR-L
IF:
     Major work items involved with the project include
     {Concrete Endwall}
and: The factors affecting the production rate of concrete
     endwall include {Utilities Relocation}
THEN:
     [Ul] IS GIVEN THE VALUE [UL]
ELSE:
     [Ul] IS GIVEN THE VALUE 1
```

```
/*   RULE NUMBER: 95
RULE: PR-FACT-EC-L
IF:
      Major work items involved with the project include
      {Concrete Endwall}
and:  The factors affecting the production rate of concrete
      endwall include {Environment Concerns}
THEN:
      [El] IS GIVEN THE VALUE [EL]
ELSE:
      [El] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 96
RULE: PR-FACT-OTHER-L
IF:
      Major work items involved with the project include
      {Concrete Endwall}
and:  The factors affecting the production rate of concrete
      endwall include {Other Unmentioned Factors}
THEN:
      [OTHl] IS GIVEN THE VALUE [OTHL]
ELSE:
      [OTHl] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 97
RULE: PR-FACT-NONE-L
IF:
      Major work items involved with the project include
      {Concrete Endwall}
and:  The factors affecting the production rate of concrete
      endwall include {None of Above}
THEN:
      [Wl] IS GIVEN THE VALUE 1
and:  [Tl] IS GIVEN THE VALUE 1
and:  [Ol] IS GIVEN THE VALUE 1
and:  [Ml] IS GIVEN THE VALUE 1
and:  [Nl] IS GIVEN THE VALUE 1
and:  [Pl] IS GIVEN THE VALUE 1
and:  [Ul] IS GIVEN THE VALUE 1
and:  [El] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 98
RULE: PR-FACT-WI-D
IF:
      Major work items involved with the project include
      {Drainage}
and:  The factors affecting the production rate of drainage
      include {Weather Impact}
THEN:
```

```
        [Wd] IS GIVEN THE VALUE [WD]
ELSE:
        [Wd] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 99
RULE: PR-FACT-TF-D
IF:
        Major work items involved with the project include
        {Drainage}
and:    The factors affecting the production rate of drainage
        include {Traffic Flow}
THEN:
        [Td] IS GIVEN THE VALUE [TD]
ELSE:
        [Td] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 100
RULE: PR-FACT-PL-D
IF:
        Major work items involved with the project include
        {Drainage}
and:    The factors affecting the production rate of drainage
        include {Project Location}
THEN:
        [Od] IS GIVEN THE VALUE [OD]
ELSE:
        [Od] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 101
RULE: PR-FACT-MD-D
IF:
        Major work items involved with the project include
        {Drainage}
and:    The factors affecting the production rate of drainage
        include {Material Delivery}
THEN:
        [Md] IS GIVEN THE VALUE [MD]
ELSE:
        [Md] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 102
RULE: PR-FACT-NW-D
IF:
        Major work items involved with the project include
        {Drainage}
and:    The factors affecting the production rate of drainage
        include {Night Work}
THEN:
```

```
        [Nd] IS GIVEN THE VALUE [ND]
ELSE:
        [Nd] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 103
RULE: PR-FACT-VP-D
IF:
        Major work items involved with the project include
        {Drainage}
and:    The factors affecting the production rate of drainage
        include {Various Permits}
THEN:
        [Pd] IS GIVEN THE VALUE [PD]
ELSE:
        [Pd] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 104
RULE: PR-FACT-SI-D
IF:
        Major work items involved with the project include
        {Drainage}
and:    The factors affecting the production rate of drainage
        include {Special Items}
THEN:
        [Sd] IS GIVEN THE VALUE [SD]
ELSE:
        [Sd] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 105
RULE: PR-FACT-OC-C
IF:
        Major work items involved with the project include
        {Drainage}
and:    The factors affecting the production rate of drainage
        include {Operation Conflicting}
THEN:
        [Xc] IS GIVEN THE VALUE [XC]
ELSE:
        [Xc] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 106
RULE: PR-FACT-UR-D
IF:
        Major work items involved with the project include
        {Drainage}
and:    The factors affecting the production rate of drainage
        include {Utilities Relocation}
THEN:
```

```
      [Ud] IS GIVEN THE VALUE [UD]
ELSE:
      [Ud] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 107
RULE: PR-FACT-EC-D

IF:
      Major work items involved with the project include
      {Drainage}
and:  The factors affecting the production rate of drainage
      include {Environment Concerns}
THEN:
      [Ed] IS GIVEN THE VALUE [ED]
ELSE:
      [Ed] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 108
RULE: PR-FACT-OTHER-D
IF:
      Major work items involved with the project include
      {Drainage}
and:  The factors affecting the production rate of drainage
      include {Other Unmentioned Factors}
THEN:
      [OTHd] IS GIVEN THE VALUE [OTHD]
ELSE:
      [OTHd] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 109
RULE: PR-FACT-NONE-D

IF:
      Major work items involved with the project include
      {Drainage}
and:  The factors affecting the production rate of drainage
      include {None of Above}
THEN:
      [Wd] IS GIVEN THE VALUE 1
and:  [Td] IS GIVEN THE VALUE 1
and:  [Od] IS GIVEN THE VALUE 1
and:  [Md] IS GIVEN THE VALUE 1
and:  [Nd] IS GIVEN THE VALUE 1
and:  [Pd] IS GIVEN THE VALUE 1
and:  [Sd] IS GIVEN THE VALUE 1
and:  [Xc] IS GIVEN THE VALUE 1
and:  [Ud] IS GIVEN THE VALUE 1
and:  [Ed] IS GIVEN THE VALUE 1
```

```
/*  RULE NUMBER: 110
RULE: PR-FACT-WI-G
IF:
        Major work items involved with the project include
        {Stabilization Roadbed}
and:    The factors affecting the production rate of
        stabilization roadbed include {Weather Impact}
THEN:
        [Wg] IS GIVEN THE VALUE [WG]
ELSE:
        [Wg] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 111
RULE: PR-FACT-TF-G
IF:
        Major work items involved with the project include
        {Stabilization Roadbed}
and:    The factors affecting the production rate of
        stabilization roadbed include {Traffic Flow}
THEN:
        [Tg] IS GIVEN THE VALUE [TG]
ELSE:
        [Tg] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 112
RULE: PR-FACT-PL-G
IF:
        Major work items involved with the project include
        {Stabilization Roadbed}
and:    The factors affecting the production rate of
        stabilization roadbed include {Project Location}
THEN:
        [Og] IS GIVEN THE VALUE [OG]
ELSE:
        [Og] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 113
RULE: PR-FACT-UR-G
IF:
        Major work items involved with the project include
        {Stabilization Roadbed}
and:    The factors affecting the production rate of
        stabilization roadbed include {Utilities Relocation}
THEN:
        [Ug] IS GIVEN THE VALUE [UG]
ELSE:
        [Ug] IS GIVEN THE VALUE 1
```

```
/*   RULE NUMBER: 114
RULE: PR-FACT-EC-G
IF:
        Major work items involved with the project include
        {Stabilization Roadbed}
and:    The factors affecting the production rate of
        stabilization roadbed include {Environment Concerns}
THEN:
        [Eg] IS GIVEN THE VALUE [EG]
ELSE:
        [Eg] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 115
RULE: PR-FACT-OTHER-G
IF:
        Major work items involved with the project include
        {Stabilization Roadbed}
and:    The factors affecting the production rate of
        stabilization roadbed include {Other Unmentioned
        Factors}
THEN:
        [OTHg] IS GIVEN THE VALUE [OTHG]
ELSE:
        [OTHg] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 116
RULE: PR-FACT-NONE-G
IF:
        Major work items involved with the project include
        {Stabilization Roadbed}
and:    The factors affecting the production rate of
        stabilization roadbed include {None of Above}

THEN:
        [Og] IS GIVEN THE VALUE 1
and:    [Ug] IS GIVEN THE VALUE 1
and:    [Eg] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 117
RULE: PR-FACT-WI-T
IF:
        Major work items involved with the project include
        {Curb/Gutter}
and:    The factors affecting the production rate of
        curb/gutter include {Weather Impact}
THEN:
        [Wt] IS GIVEN THE VALUE [WT]
ELSE:
        [Wt] IS GIVEN THE VALUE 1
```

```
/*   RULE NUMBER: 118
RULE: PR-FACT-MD-T
IF:
        Major work items involved with the project include
        {Curb/Gutter}
and:    The factors affecting the production rate of
        curb/gutter include {Material Delivery}
THEN:
        [Mt] IS GIVEN THE VALUE [MT]
ELSE:
        [Mt] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 119
RULE: PR-FACT-NW-T
IF:
        Major work items involved with the project include
        {Curb/Gutter}
and:    The factors affecting the production rate of
        curb/gutter include {Night Work}
THEN:
        [Nt] IS GIVEN THE VALUE [NT]
ELSE:
        [Nt] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 120
RULE: PR-FACT-WDT-T
IF:
        Major work items involved with the project include
        {Curb/Gutter}
and:    The factors affecting the production rate of
        curb/gutter include {Waiting & Delay Time}

THEN:
        [At] IS GIVEN THE VALUE [AT]
ELSE:
        [At] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 121
RULE: PR-FACT-UR-T
IF:
        Major work items involved with the project include
        {Curb/Gutter}
and:    The factors affecting the production rate of
        curb/gutter include {Utilities Relocation}
THEN:
        [Ut] IS GIVEN THE VALUE [UT]
ELSE:
        [Ut] IS GIVEN THE VALUE 1
```

```
/*  RULE NUMBER: 122
RULE: PR-FACT-OTHER-T
IF:
      Major work items involved with the project include
      {Curb/Gutter}
and:  The factors affecting the production rate of
      curb/gutter include {Other Unmentioned Factors}
THEN:
      [OTHt] IS GIVEN THE VALUE [OTHT]
ELSE:
      [OTHt] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 123
RULE: PR-FACT-NONE-T
IF:
      Major work items involved with the project include
      {Curb/Gutter}
and:  The factors affecting the production rate of
      curb/gutter include {None of Above}
THEN:
      [Mt] IS GIVEN THE VALUE 1
and:  [Wt] IS GIVEN THE VALUE 1
and:  [Nt] IS GIVEN THE VALUE 1
and:  [At] IS GIVEN THE VALUE 1
and:  [Ut] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 124
RULE: PR-FACT-WI-B
IF:
      Major work items involved with the project include
      {Base Construction}
and:  The factors affecting the production rate of base
      construction include {Weather Impact}
THEN:
      [Wb] IS GIVEN THE VALUE [WB]
ELSE:
      [Wb] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 125
RULE: PR-FACT-TF-B
IF:
      Major work items involved with the project include
      {Base Construction}
and:  The factors affecting the production rate of base
      construction include {Traffic Flow}
THEN:
      [Tb] IS GIVEN THE VALUE [TB]
ELSE:
      [Tb] IS GIVEN THE VALUE 1
```

```
/*  RULE NUMBER: 126
RULE: PR-FACT-PL-B
IF:
        Major work items involved with the project include
        {Base Construction}
and:    The factors affecting the production rate of base
        construction include {Project Location}
THEN:
        [Ob] IS GIVEN THE VALUE [OB]
ELSE:
        [Ob] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 127
RULE: PR-FACT-UR-B
IF:
        Major work items involved with the project include
        {Base Construction}
and:    The factors affecting the production rate of base
        construction include {Utilities Relocation}
THEN:
        [Ub] IS GIVEN THE VALUE [UB]
ELSE:
        [Ub] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 128
RULE: PR-FACT-EC-B
IF:
        Major work items involved with the project include
        {Base Construction}
and:    The factors affecting the production rate of base
        construction include {Environment Concerns}
THEN:
        [Eb] IS GIVEN THE VALUE [EB]
ELSE:
        [Eb] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 129
RULE: PR-FACT-OTHER-B
IF:
        Major work items involved with the project include
        {Base Construction}
and:    The factors affecting the production rate of base
        construction include {Other Unmentioned Factors}
THEN:
        [OTHb] IS GIVEN THE VALUE [OTHB]
ELSE:
        [OTHb] IS GIVEN THE VALUE 1
```

```
/*  RULE NUMBER: 130
RULE: PR-FACT-NONE-B
IF:
        Major work items involved with the project include
        {Base Construction}
and:    The factors affecting the production rate of base
        construction include {None of Above}
THEN:
        [Wb] IS GIVEN THE VALUE 1
and:    [Tb] IS GIVEN THE VALUE 1
and:    [Ob] IS GIVEN THE VALUE 1
and:    [Ub] IS GIVEN THE VALUE 1
and:    [Eb] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 131
RULE: PR-FACT-WI-M
IF:
        Major work items involved with the project include
        {Milling Exist Pavement}
and:    The factors affecting the production rate of milling
        exist pavement include {Weather Impact}
THEN:
        [Wm] IS GIVEN THE VALUE [WM]
ELSE:
        [Wm] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 132
RULE: PR-FACT-TF-M
IF:
        Major work items involved with the project include
        {Milling Exist Pavement}
and:    The factors affecting the production rate of milling
        exist pavement include {Traffic Flow}
THEN:
        [Tm] IS GIVEN THE VALUE [TM]
ELSE:
        [Tm] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 133
RULE: PR-FACT-PL-M
IF:
        Major work items involved with the project include
        {Milling Exist Pavement}
and:    The factors affecting the production rate of milling
        exist pavement include {Project Location}
THEN:
        [Om] IS GIVEN THE VALUE [OM]
ELSE:
        [Om] IS GIVEN THE VALUE 1
```

```
/*  RULE NUMBER: 134
RULE: PR-FACT-PT-M
IF:
      Major work items involved with the project include
      {Milling Exist Pavement}
and:  The factors affecting the production rate of milling
      exist pavement include {Dominant Project Type}
THEN:
      [Dm] IS GIVEN THE VALUE [DM]
ELSE:
      [Dm] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 135
RULE: PR-FACT-OTHER-M
IF:
      Major work items involved with the project include
      {Milling Exist Pavement}
and:  The factors affecting the production rate of milling
      exist pavement include {Other Unmentioned Factors}
THEN:
      [OTHm] IS GIVEN THE VALUE [OTHM]
ELSE:
      [OTHm] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 136
RULE: PR-FACT-NONE-M
IF:
      Major work items involved with the project include
      {Milling Exist Pavement}
and:  The factors affecting the production rate of milling
      exist pavement include {None of Above}
THEN:
      [Wm] IS GIVEN THE VALUE 1
and:  [Tm] IS GIVEN THE VALUE 1
and:  [Om] IS GIVEN THE VALUE 1
and:  [Dm] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 137
RULE: PR-FACT-WI-S
IF:
      Major work items involved with the project include
      {Asphalt-Structural}
and:  The factors affecting the production rate of
      asphalt-structural include {Weather Impact}
THEN:
      [Ws] IS GIVEN THE VALUE [WS]
ELSE:
      [Ws] IS GIVEN THE VALUE 1
```

```
/*  RULE NUMBER: 138
RULE: PR-FACT-TF-S
IF:
      Major work items involved with the project include
      {Asphalt-Structural}
and:  The factors affecting the production rate of
      asphalt-structural include {Traffic Flow}
THEN:
      [Ts] IS GIVEN THE VALUE [TS]
ELSE:
      [Ts] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 139
RULE: PR-FACT-PL-S
IF:
      Major work items involved with the project include
      {Asphalt-Structural}
and:  The factors affecting the production rate of
      asphalt-structural include {Project Location}
THEN:
      [Os] IS GIVEN THE VALUE [OS]
ELSE:
      [Os] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 140
RULE: PR-FACT-MD-S

IF:
      Major work items involved with the project include
      {Asphalt-Structural}
and:  The factors affecting the production rate of
      asphalt-structural include {Material Delivery}
THEN:
      [Ms] IS GIVEN THE VALUE [MS]
ELSE:
      [Ms] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 141
RULE: PR-FACT-PLT-S
IF:
      Major work items involved with the project include
      {Asphalt-Structural}
and:  The factors affecting the production rate of
      asphalt-structural include {Project Letting Time}
THEN:
      [Ls] IS GIVEN THE VALUE [LS]
ELSE:
      [Ls] IS GIVEN THE VALUE 1
```

```
/*  RULE NUMBER: 142
RULE: PR-FACT-LS-S
IF:
      Major work items involved with the project include
      {Asphalt-Structural}
and:  The factors affecting the production rate of
      asphalt-structural include {Legal Aspects}
THEN:
      [Gs] IS GIVEN THE VALUE [GS]
ELSE:
      [Gs] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 143
RULE: PR-FACT-PT-S
IF:
      Major work items involved with the project include
      {Asphalt-Structural}
and:  The factors affecting the production rate of
      asphalt-structural include {Dominant Project Type}
THEN:
      [Ds] IS GIVEN THE VALUE [DS]
ELSE:
      [Ds] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 144
RULE: PR-FACT-OTHER-S

IF:
      Major work items involved with the project include
      {Asphalt-Structural}
and:  The factors affecting the production rate of
      asphalt-structural include {Other Unmentioned Factors}
THEN:
      [OTHs] IS GIVEN THE VALUE [OTHS]
ELSE:
      [OTHs] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 145
RULE: PR-FACT-NONE-S
IF:
      Major work items involved with the project include
      {Asphalt-Structural}
and:  The factors affecting the production rate of
      asphalt-structural include {None of Above}
THEN:
      [Ws] IS GIVEN THE VALUE 1
and:  [Ts] IS GIVEN THE VALUE 1
and:  [Os] IS GIVEN THE VALUE 1
and:  [Ms] IS GIVEN THE VALUE 1
```

```
and:    [Ls] IS GIVEN THE VALUE 1
and:    [Gs] IS GIVEN THE VALUE 1
and:    [Ds] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 146
RULE: PR-FACT-WI-A
IF:
        Major work items involved with the project include
        {Sidewalk}
and:    The factors affecting the production rate of sidewalk
        include {Weather Impact}
THEN:
        [Wa] IS GIVEN THE VALUE [WA]
ELSE:
        [Wa] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 147
RULE: PR-FACT-PL-A
IF:
        Major work items involved with the project include
        {Sidewalk}
and:    The factors affecting the production rate of sidewalk
        include {Project Location}
THEN:
        [Oa] IS GIVEN THE VALUE [OA]
ELSE:
        [Oa] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 148
RULE: PR-FACT-MD-A
IF:
        Major work items involved with the project include
        {Sidewalk}
and:    The factors affecting the production rate of sidewalk
        include {Material Delivery}
THEN:
        [Ma] IS GIVEN THE VALUE [MA]
ELSE:
        [Ma] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 149
RULE: PR-FACT-NW-O
IF:
        Major work items involved with the project include
        {Sidewalk}
and:    The factors affecting the production rate of sidewalk
        include {Night Work}
```

```
THEN:
      [No] IS GIVEN THE VALUE [NO]
ELSE:
      [No] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 150
RULE: PR-FACT-UR-A
IF:
      Major work items involved with the project include
      {Sidewalk}
and:  The factors affecting the production rate of sidewalk
      include {Utilities Relocation}
THEN:
      [Ua] IS GIVEN THE VALUE [UA]
ELSE:
      [Ua] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 151
RULE: PR-FACT-OTHER-A
IF:
      Major work items involved with the project include
      {Sidewalk}
and:  The factors affecting the production rate of sidewalk
      include {Other Unmentioned Factors}
THEN:
      [OTHa] IS GIVEN THE VALUE [OTHA]
ELSE:
      [OTHa] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 152
RULE: PR-FACT-NONE-A
IF:
      Major work items involved with the project include
      {Sidewalk}
and:  The factors affecting the production rate of sidewalk
      include {None of Above}
THEN:
      [Wa] IS GIVEN THE VALUE 1
and:  [Oa] IS GIVEN THE VALUE 1
and:  [Ma] IS GIVEN THE VALUE 1
and:  [No] IS GIVEN THE VALUE 1
and:  [Ua] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 153
RULE: PR-FACT-WI-E
IF:
      Major work items involved with the project include
      {Seeding}
```

```
and:    The factors affecting the production rate of seeding
        include {Weather Impact}
THEN:
        [We] IS GIVEN THE VALUE [WE]
ELSE:
        [We] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 154
RULE: PR-FACT-MD-E
IF:
        Major work items involved with the project include
        {Seeding}
and:    The factors affecting the production rate of seeding
        include {Material Delivery}
THEN:
        [Me] IS GIVEN THE VALUE [ME]
ELSE:
        [Me] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 155
RULE: PR-FACT-OC-E
IF:
        Major work items involved with the project include
        {Seeding}
and:    The factors affecting the production rate of seeding
        include {Operation Conflicting}
THEN:
        [Ce] IS GIVEN THE VALUE [CE]
ELSE:
        [Ce] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 156
RULE: PR-FACT-UR-E
IF:
        Major work items involved with the project include
        {Seeding}
and:    The factors affecting the production rate of seeding
        include {Utilities Relocation}
THEN:
        [Ue] IS GIVEN THE VALUE [UE]
ELSE:
        [Ue] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 157
RULE: PR-FACT-OTHER-E
IF:
        Major work items involved with the project include
        {Seeding}
```

```
and:    The factors affecting the production rate of seeding
        include {Other Unmentioned Factors}
THEN:
        [OTHe] IS GIVEN THE VALUE [OTHE]
ELSE:
        [OTHe] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 158
RULE: PR-FACT-NONE-E
IF:
        Major work items involved with the project include
        {Seeding}
and:    The factors affecting the production rate of seeding
        include {None of Above}
THEN:
        [We] IS GIVEN THE VALUE 1
and:    [Me] IS GIVEN THE VALUE 1
and:    [Ce] IS GIVEN THE VALUE 1
and:    [Ue] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 159
RULE: PR-FACT-WI-O
IF:
        Major work items involved with the project include
        {Sodding}
and:    The factors affecting the production rate of sodding
        include {Weather Impact}
THEN:
        [Wo] IS GIVEN THE VALUE [WO]

ELSE:
        [Wo] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 160
RULE: PR-FACT-MD-O
IF:
        Major work items involved with the project include
        {Sodding}
and:    The factors affecting the production rate of sodding
        include {Material Delivery}
THEN:
        [Mo] IS GIVEN THE VALUE [MO]
ELSE:
        [Mo] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 161
RULE: PR-FACT-OC-O
IF:
```

```
        Major work items involved with the project include
        {Sodding}
and:    The factors affecting the production rate of sodding
        include {Operation Conflicting}
THEN:
        [Co] IS GIVEN THE VALUE [CO]
ELSE:
        [Co] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 162
RULE: PR-FCT-UR-O
IF:
        Major work items involved with the project include
        {Sodding}
and:    The factors affecting the production rate of sodding
        include {Utilities Relocation}
THEN:
        [Uo] IS GIVEN THE VALUE [UO]
ELSE:
        [Uo] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 163
RULE: PR-FACT-OTHER-O
IF:
        Major work items involved with the project include
        {Sodding}
and:    The factors affecting the production rate of sodding
        include {Other Unmentioned Factors}
THEN:
        [OTHo] IS GIVEN THE VALUE [OTHO]

ELSE:
        [OTHo] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 164
RULE: PR-FACT-NONE-O
IF:
        Major work items involved with the project include
        {Sodding}
and:    The factors affecting the production rate of sodding
        include {None of Above}
THEN:
        [Wo] IS GIVEN THE VALUE 1
and:    [Mo] IS GIVEN THE VALUE 1
and:    [Co] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 165
RULE: PR-FACT-WI-N
```

```
IF:
      Major work items involved with the project include
      {Fence}
and:  The factors affecting the production rate of fence
      include {Weather Impact}
THEN:
      [Wn] IS GIVEN THE VALUE [WN]
ELSE:
      [Wn] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 166
RULE: PR-FACT-MD-N
IF:
      Major work items involved with the project include
      {Fence}
and:  The factors affecting the production rate of fence
      include {Material Delivery}
THEN:
      [Mn] IS GIVEN THE VALUE [WN]
ELSE:
      [Mn] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 167
RULE: PR-FACT-LA-N
IF:
      Major work items involved with the project include
      {Fence}
and:  The factors affecting the production rate of fence
      include {Legal Aspects}
THEN:
      [Gn] IS GIVEN THE VALUE [GN]
ELSE:
      [Gn] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 168
RULE: PR-FACT-OTHER-N
IF:
      Major work items involved with the project include
      {Fence}
and:  The factors affecting the production rate of fence
      include {Other Unmentioned Factors}
THEN:
      [OTHn] IS GIVEN THE VALUE [OTHN]
ELSE:
      [OTHn] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 169
RULE: PR-FCAT-NONE-N
```

```
IF:
      Major work items involved with the project include
      {Fence}
and:  The factors affecting the production rate of fence
      include {None of Above}
THEN:
      [Wn] IS GIVEN THE VALUE 1
and:  [Mn] IS GIVEN THE VALUE 1
and:  [Gn] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 170
RULE: PR-FACT-WI-U
IF:
      Major work items involved with the project include
      {Guardrail}
and:  The factors affecting the production rate of guardrail
      include {Weather Impact}
THEN:
      [Wu] IS GIVEN THE VALUE [WU]
ELSE:
      [Wu] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 171
RULE: PR-FACT-MD-U
IF:
      Major work items involved with the project include
      {Guardrail}
and:  The factors affecting the production rate of guardrail
      include {Material Delivery}
THEN:
      [Mu] IS GIVEN THE VALUE [MU]
ELSE:
      [Mu] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 172
RULE: PR-FACT-SI-U
IF:
      Major work items involved with the project include
      {Guardrail}
and:  The factors affecting the production rate of guardrail
      include {Special Items}
THEN:
      [Su] IS GIVEN THE VALUE [SU]
ELSE:
      [Su] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 173
RULE: PR-FACT-OTHER-U
```

```
IF:
      Major work items involved with the project include
      {Guardrail}
and:  The factors affecting the production rate of guardrail
      include {Other Unmentioned Factors}
THEN:
      [OTHu] IS GIVEN THE VALUE [OTHU]
ELSE:
      [OTHu] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 174
RULE: PR-FACT-NONE-U
IF:
      Major work items involved with the project include
      {Guardrail}
and:  The factors affecting the production rate of guardrail
      include {None of Above}
THEN:
      [Wu] IS GIVEN THE VALUE 1
and:  [Mu] IS GIVEN THE VALUE 1
and:  [Su] IS GIVEN THE VALUE 1
and:  [Cu] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 175
RULE: PR-FACT-OC-U
IF:
      Major work items involved with the project include
      {Guardrail}
and:  The factors affecting the production rate of guardrail
      include {Operation Conflicting}
THEN:
      [Cu] IS GIVEN THE VALUE [CU]
ELSE:
      [Cu] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 176
RULE: PR-FACT-WI-F
IF:
      Major work items involved with the project include
      {Asphalt-Friction}
and:  The factors affecting the production rate of
      asphalt-friction include {Weather Impact}
THEN:
      [Wf] IS GIVEN THE VALUE [WF]
and:  [Tf] IS GIVEN THE VALUE [TF]
and:  [Of] IS GIVEN THE VALUE [OF]
and:  [Mf] IS GIVEN THE VALUE [MF]
and:  [Lf] IS GIVEN THE VALUE [LF]
and:  [Gf] IS GIVEN THE VALUE [GF]
```

```
and:    [Df] IS GIVEN THE VALUE [DF]
ELSE:
        [Wf] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 177
RULE: PR-FACT-TF-F
IF:
        Major work items involved with the project include
        {Asphalt-Friction}
and:    The factors affecting the production rate of
        asphalt-friction include {Traffic Flow}
THEN:
        [Tf] IS GIVEN THE VALUE [TF]
ELSE:
        [Tf] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 178
RULE: PR-FACT-PL-F
IF:
        Major work items involved with the project include
        {Asphalt-Friction}
and:    The factors affecting the production rate of
        asphalt-friction include {Project Location}
THEN:
        [Of] IS GIVEN THE VALUE [OF]
ELSE:
        [Of] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 179
RULE: PR-FACT-MD-F
IF:
        Major work items involved with the project include
        {Asphalt-Friction}
and:    The factors affecting the production rate of
        asphalt-friction include {Material Delivery}
THEN:
        [Mf] IS GIVEN THE VALUE [MF]
ELSE:
        [Mf] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 180
RULE: PR-FACT-PLT-F
IF:
        Major work items involved with the project include
        {Asphalt-Friction}
and:    The factors affecting the production rate of
        asphalt-friction include {Project Letting Time}
THEN:
```

```
        [Lf] IS GIVEN THE VALUE [LF]
ELSE:
        [Lf] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 181
RULE: PR-FACT-LA-F
IF:
        Major work items involved with the project include
        {Asphalt-Friction}
and:    The factors affecting the production rate of
        asphalt-friction include {Legal Aspects}
THEN:
        [Gf] IS GIVEN THE VALUE [GF]
ELSE:
        [Gf] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 182
RULE: PR-FACT-PT-F
IF:
        Major work items involved with the project include
        {Asphalt-Friction}
and:    The factors affecting the production rate of
        asphalt-friction include {Dominant Project Type}
THEN:
        [Df] IS GIVEN THE VALUE [DF]
ELSE:
        [Df] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 183
RULE: PR-FACT-OTHER-F

IF:
        Major work items involved with the project include
        {Asphalt-Friction}
and:    The factors affecting the production rate of
        asphalt-friction include {Other Unmentioned Factors}
THEN:
        [OTHf] IS GIVEN THE VALUE [OTHF]
ELSE:
        [OTHf] IS GIVEN THE VALUE 1


/*  RULE NUMBER: 184
RULE: PR-FACT-NONE-F
IF:
        Major work items involved with the project include
        {Asphalt-Friction}
and:    The factors affecting the production rate of
        asphalt-friction include {None of Above}
```

```
THEN:
        [Wf] IS GIVEN THE VALUE 1
and:    [Tf] IS GIVEN THE VALUE 1
and:    [Of] IS GIVEN THE VALUE 1
and:    [Mf] IS GIVEN THE VALUE 1
and:    [Lf] IS GIVEN THE VALUE 1
and:    [Gf] IS GIVEN THE VALUE 1
and:    [Df] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 185
RULE: PR-FACT-WI-P
IF:
        Major work items involved with the project include
        {Stripping}
and:    The factors affecting the production rate of stripping
        include {Weather Impact}
THEN:
        [Wp] IS GIVEN THE VALUE [WP]
ELSE:
        [Wp] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 186
RULE: PR-FACT-TF-P
IF:
        Major work items involved with the project include
        {Stripping}
and:    The factors affecting the production rate of stripping
        include {Traffic Flow}
THEN:
        [Tp] IS GIVEN THE VALUE [TP]
ELSE:
        [Tp] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 187
RULE: PR-FACT-OTHER-P
IF:
        Major work items involved with the project include
        {Stripping}
and:    The factors affecting the production rate of stripping
        include {Other Unmentioned Factors}
THEN:
        [OTHp] IS GIVEN THE VALUE [OTHP]
ELSE:
        [OTHp] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 188
RULE: PR-FACT-NONE-P
IF:
```

```
        Major work items involved with the project include
        {Stripping}
and:    The factors affecting the production rate of stripping
        include {None of Above}
THEN:
        [Wp] IS GIVEN THE VALUE 1
and:    [Tp] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 189
RULE: PR-FACT-WI-R
IF:
        Major work items involved with the project include
        {RPM's}
and:    The factors affecting the production rate of RPM's
        include {Weather Impact}
THEN:
        [Wr] IS GIVEN THE VALUE [WR]
ELSE:
        [Wr] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 190
RULE: PR-FACT-TF-R
IF:
        Major work items involved with the project include
        {RPM's}
and:    The factors affecting the production rate of RPM's
        include {Traffic Flow}
THEN:
        [Tr] IS GIVEN THE VALUE [TR]
ELSE:
        [Tr] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 191
RULE: PR-FACT-OTHER-R
IF:
        Major work items involved with the project include
        {RPM's}
and:    The factors affecting the production rate of RPM's
        include {Other Unmentioned Factors}
THEN:
        [OTHr] IS GIVEN THE VALUE [OTHR]
ELSE:
        [OTHr] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 192
RULE: PR-FACT-NONE-R
IF:
        Major work items involved with the project include
```

```
        {RPM's}
and:    The factors affecting the production rate of RPM's
        include {None of Above}
THEN:
        [Wr] IS GIVEN THE VALUE 1
and:    [Tr] IS GIVEN THE VALUE 1


/*   RULE NUMBER: 193
RULE: PR-GEN-MOB
IF:
        It is {necessary to assign duration for project
        mobilization}
THEN:
        [z] IS GIVEN THE VALUE [Z]
and:    [Fc] IS GIVEN THE VALUE
        [WC]*[OC]*[NC]*[PC]*[GC]*[CC]*[UC]*[EC]
and:    [Fv] IS GIVEN THE VALUE
        [WV]*[OV]*[NV]*[PV]*[UV]*[DV]*[EV]
and:    [Fw] IS GIVEN THE VALUE
        [WW]*[OW]*[NW]*[PW]*[UW]*[DW]*[EW]
and:    [Fy] IS GIVEN THE VALUE
        [WY]*[TY]*[OY]*[MY]*[NY]*[LY]*[SY]*[UY]*[EY]
and:    [Fl] IS GIVEN THE VALUE
        [WL]*[TL]*[OL]*[ML]*[NL]*[PL]*[UL]*[EL]
and:    [Fd] IS GIVEN THE VALUE
        [WD]*[TD]*[OD]*[MD]*[ND]*[PD]*[SD]*[XC]*[UD]*[ED]
and:    [Fg] IS GIVEN THE VALUE [WG]*[TG]*[OG]*[UG]*[EG]
and:    [Ft] IS GIVEN THE VALUE [WT]*[MT]*[NT]*[AT]*[UT]
and:    [Fb] IS GIVEN THE VALUE [WB]*[TB]*[OB]*[UB]*[EB]
and:    [Fm] IS GIVEN THE VALUE [WM]*[TM]*[OM]*[DM]
and:    [Fs] IS GIVEN THE VALUE
        [WS]*[TS]*[OS]*[MS]*[LS]*[GS]*[DS]
and:    [Fa] IS GIVEN THE VALUE [WA]*[OS]*[MA]*[NO]*[UA]
and:    [Fe] IS GIVEN THE VALUE [WE]*[ME]*[CE]*[UE]
and:    [Fo] IS GIVEN THE VALUE [WO]*[MO]*[CO]*[UO]
and:    [Fn] IS GIVEN THE VALUE [WN]*[MN]*[GN]
and:    [Fu] IS GIVEN THE VALUE [WU]*[MU]*[SU]*[CU]
and:    [Ff] IS GIVEN THE VALUE
        [WF]*[TF]*[OF]*[MF]*[LF]*[GF]*[DF]
and:    [Fp] IS GIVEN THE VALUE [WP]*[TP]
and:    [Fr] IS GIVEN THE VALUE [WR]*[TR]
and:    X> SS_WR(c:\exsysp\cftab.wk1, f5, [z], f6, [Fc], f7,
        [Fy], f8, [Fl], f9, [Fg], f10, [Fm], f11, [Fd], f12,
        [Fa], f13, [Ft], f14, [Fe], f15, [Fo], f16, [Fu], f17,
        [Fp])
and:    X> SS_WR(c:\exsysp\cfcht.wk1, f5, [Fv], f6, [Fw], f7,
        [Fb], f8, [Fs], f9, [Ff], f10, [Fr], f11, [Fn])
and:    X> SS_WR(c:\exsysp\prcht.wk1, h5, [Qv], h6, [Qw], h7,
        [Qb], h8, [Qs], h9, [Qf], h10, [Qr], h11, [Qn])
and:    X> SS_WR(c:\exsysp\prtab.wk1, h7, [Qc], h8, [Qy], h9,
        [Ql], h10, [Qg], h11, [Qm], h12, [Qd], h13, [Qa], h14,
```

```
            [Qt], h15, [Qe], h16, [Qo], h17, [Qu], h18, [Qp])
ELSE:
            [z] IS GIVEN THE VALUE 0
and:        [Fc] IS GIVEN THE VALUE
            [WC]*[OC]*[NC]*[PC]*[GC]*[CC]*[UC]*[EC]
and:        [Fv] IS GIVEN THE VALUE
            [WV]*[OV]*[NV]*[PV]*[UV]*[DV]*[EV]
and:        [Fw] IS GIVEN THE VALUE
            [WW]*[OW]*[NW]*[PW]*[UV]*[DW]*[EW]
and:        [Fy] IS GIVEN THE VALUE
            [WY]*[TY]*[OY]*[MY]*[NY]*[LY]*[SY]*[UY]*[EY]
and:        [Fl] IS GIVEN THE VALUE
            [WL]*[TL]*[OL]*[ML]*[NL]*[PL]*[UL]*[EL]
and:        [Fd] IS GIVEN THE VALUE
            [WD]*[TD]*[OD]*[MD]*[ND]*[PD]*[SD]*[XC]*[UD]*[ED]
and:        [Fg] IS GIVEN THE VALUE [WG]*[TG]*[OG]*[UG]*[EG]
and:        [Ft] IS GIVEN THE VALUE [WT]*[MT]*[NT]*[AT]*[UT]
and:        [Fb] IS GIVEN THE VALUE [WB]*[TB]*[OB]*[UB]*[EB]
and:        [Fm] IS GIVEN THE VALUE [WM]*[TM]*[OM]*[DM]
and:        [Fs] IS GIVEN THE VALUE
            [WS]*[TS]*[OS]*[MS]*[LS]*[GS]*[DS]
and:        [Fa] IS GIVEN THE VALUE [WA]*[OA]*[MA]*[NO]*[UA]
and:        [Fe] IS GIVEN THE VALUE [WE]*[ME]*[CE]*[UE]
and:        [Fo] IS GIVEN THE VALUE [WO]*[MO]*[CO]*[UO]
and:        [Fn] IS GIVEN THE VALUE [WN]*[MN]*[GN]
and:        [Fu] IS GIVEN THE VALUE [WU]*[MU]*[SU]*[CU]
and:        [Ff] IS GIVEN THE VALUE
            [WF]*[TF]*[OF]*[MF]*[LF]*[GF]*[DF]
and:        [Fp] IS GIVEN THE VALUE [WP]*[TP]
and:        [Fr] IS GIVEN THE VALUE [WR]*[TR]
and:        X> SS_WR(c:\exsysp\cftab.wk1, f5, [z], f6, [Fc], f7,
            [Fy], f8, [Fl], f9, [Fg], f10, [Fm], f11, [Fd], f12,
            [Fa], f13, [Ft], f14, [Fe], f15, [Fo], f16, [Fu], f17,
            [Fp])
and:        X> SS_WR(c:\exsysp\cfcht.wk1, f5, [Fv], f6, [Fw], f7,
            [Fb], f8, [Fs], f9, [Ff], f10, [Fr], f11, [Fn])
and:        X> SS_WR(c:\exsysp\prcht.wk1, h5, [Qv], h6, [Qw], h7,
            [Qb], h8, [Qs], h9, [Qf], h10, [Qr], h11, [Qn])
and:        X> SS_WR(c:\exsysp\prtab.wk1, h7, [Qc], h8, [Qy], h9,
            [Ql], h10, [Qg], h11, [Qm], h12, [Qd], h13, [Qa], h14,
            [Qt], h15, [Qe], h16, [Qo], h17, [Qu], h18, [Qp])


/*   RULE NUMBER: 194
RULE: PR-GEN-SCHPROG
IF:
            The scheduling software used to estimate contract
            duration is {Suretrak 2.0}
THEN:
            X> RUN(123 /B)
and:        [Ssw] IS GIVEN THE VALUE 3
and:        X> SS_WR(c:\exsysp\auto123.wk1, a1, [Ssw])
```

```
and:    X> RUN(st /X)
and:    X> RUN(123 /B)
and:    X> SS_RD(c:\exsysp\auto123.wk1, a15, c3)
ELSE:
        X> RUN(123 /B)
```

THE "A+B" MODUEL RULES


```
/*   RULE NUMBER: 195
RULE: AB-TEN-INPUT
IF:
        To estimate contract duration, the module used is {the
        "A+B" module}
and:    The number of bidders join the bid is {Ten}
THEN:
        [Name1] IS GIVEN THE VALUE [NAME1]
and:    [WKcost1] IS GIVEN THE VALUE [WKCOST1]
and:    [Dur1] IS GIVEN THE VALUE [DUR1]
and:    [Name2] IS GIVEN THE VALUE [NAME2]
and:    [WKcost2] IS GIVEN THE VALUE [WKCOST2]
and:    [Dur2] IS GIVEN THE VALUE [DUR2]
and:    [Name3] IS GIVEN THE VALUE [NAME3]
and:    [WKcost3] IS GIVEN THE VALUE [WKCOST3]
and:    [Dur3] IS GIVEN THE VALUE [DUR3]
and:    [Name4] IS GIVEN THE VALUE [NAME4]
and:    [WKcost4] IS GIVEN THE VALUE [WKCOST4]
and:    [Dur4] IS GIVEN THE VALUE [DUR4]
and:    [Name5] IS GIVEN THE VALUE [NAME5]
and:    [WKcost5] IS GIVEN THE VALUE [WKCOST5]
and:    [Dur5] IS GIVEN THE VALUE [DUR5]
and:    [Name6] IS GIVEN THE VALUE [NAME6]
and:    [WKcost6] IS GIVEN THE VALUE [WKCOST6]
and:    [Dur6] IS GIVEN THE VALUE [DUR6]
and:    [Name7] IS GIVEN THE VALUE [NAME7]
and:    [WKcost7] IS GIVEN THE VALUE [WKCOST7]
and:    [Dur7] IS GIVEN THE VALUE [DUR7]
and:    [Name8] IS GIVEN THE VALUE [NAME8]
and:    [WKcost8] IS GIVEN THE VALUE [WKCOST8]
and:    [Dur8] IS GIVEN THE VALUE [DUR8]
and:    [Name9] IS GIVEN THE VALUE [NAME9]
and:    [WKcost9] IS GIVEN THE VALUE [WKCOST9]
and:    [Dur9] IS GIVEN THE VALUE [DUR9]
and:    [Name10] IS GIVEN THE VALUE [NAME10]
and:    [WKcost10] IS GIVEN THE VALUE [WKCOST10]
and:    [Dur10] IS GIVEN THE VALUE [DUR10]
and:    [Tbid1] IS GIVEN THE VALUE [WKCOST1]+[DUR1]*[DRUC]
and:    [Tbid2] IS GIVEN THE VALUE [WKCOST2]+[DUR2]*[DRUC]
and:    [Tbid3] IS GIVEN THE VALUE [WKCOST3]+[DUR3]*[DRUC]
and:    [Tbid4] IS GIVEN THE VALUE [WKCOST4]+[DUR4]*[DRUC]
and:    [Tbid5] IS GIVEN THE VALUE [WKCOST5]+[DUR5]*[DRUC]
and:    [Tbid6] IS GIVEN THE VALUE [WKCOST6]+[DUR6]*[DRUC]
and:    [Tbid7] IS GIVEN THE VALUE [WKCOST7]+[DUR7]*[DRUC]
and:    [Tbid8] IS GIVEN THE VALUE [WKCOST8]+[DUR8]*[DRUC]
and:    [Tbid9] IS GIVEN THE VALUE [WKCOST9]+[DUR9]*[DRUC]
and:    [Tbid10] IS GIVEN THE VALUE [WKCOST10]+[DUR10]*[DRUC]
```

```
/*   RULE NUMBER: 196
RULE: AB-NINE-INPUT
IF:
      The number of bidders join the bid is {Nine}
THEN:
      [Name1] IS GIVEN THE VALUE [NAME1]
and:  [WKcost1] IS GIVEN THE VALUE [WKCOST1]
and:  [Dur1] IS GIVEN THE VALUE [DUR1]
and:  [Name2] IS GIVEN THE VALUE [NAME2]
and:  [WKcost2] IS GIVEN THE VALUE [WKCOST2]
and:  [Dur2] IS GIVEN THE VALUE [DUR2]
and:  [Name3] IS GIVEN THE VALUE [NAME3]
and:  [WKcost3] IS GIVEN THE VALUE [WKCOST3]
and:  [Dur3] IS GIVEN THE VALUE [DUR3]
and:  [Name4] IS GIVEN THE VALUE [NAME4]
and:  [WKcost4] IS GIVEN THE VALUE [WKCOST4]
and:  [Dur4] IS GIVEN THE VALUE [DUR4]
and:  [Name5] IS GIVEN THE VALUE [NAME5]
and:  [WKcost5] IS GIVEN THE VALUE [WKCOST5]
and:  [Dur5] IS GIVEN THE VALUE [DUR5]
and:  [Name6] IS GIVEN THE VALUE [NAME6]
and:  [WKcost6] IS GIVEN THE VALUE [WKCOST6]
and:  [Dur6] IS GIVEN THE VALUE [DUR6]
and:  [Name7] IS GIVEN THE VALUE [NAME7]
and:  [WKcost7] IS GIVEN THE VALUE [WKCOST7]
and:  [Dur7] IS GIVEN THE VALUE [DUR7]
and:  [Name8] IS GIVEN THE VALUE [NAME8]
and:  [WKcost8] IS GIVEN THE VALUE [WKCOST8]
and:  [Dur8] IS GIVEN THE VALUE [DUR8]
and:  [Name9] IS GIVEN THE VALUE [NAME9]
and:  [WKcost9] IS GIVEN THE VALUE [WKCOST9]
and:  [Dur9] IS GIVEN THE VALUE [DUR9]
and:  [Tbid1] IS GIVEN THE VALUE [WKCOST1]+[DUR1]*[DRUC]
and:  [Tbid2] IS GIVEN THE VALUE [WKCOST2]+[DUR2]*[DRUC]
and:  [Tbid3] IS GIVEN THE VALUE [WKCOST3]+[DUR3]*[DRUC]
and:  [Tbid4] IS GIVEN THE VALUE [WKCOST4]+[DUR4]*[DRUC]
and:  [Tbid5] IS GIVEN THE VALUE [WKCOST5]+[DUR5]*[DRUC]
and:  [Tbid6] IS GIVEN THE VALUE [WKCOST6]+[DUR6]*[DRUC]
and:  [Tbid7] IS GIVEN THE VALUE [WKCOST7]+[DUR7]*[DRUC]
and:  [Tbid8] IS GIVEN THE VALUE [WKCOST8]+[DUR8]*[DRUC]
and:  [Tbid9] IS GIVEN THE VALUE [WKCOST9]+[DUR9]*[DRUC]


/*   RULE NUMBER: 197
RULE: AB-EIGHT-INPUT
IF:
      The number of bidders join the bid is {Eight}
THEN:
      [Name1] IS GIVEN THE VALUE [NAME1]
and:  [WKcost1] IS GIVEN THE VALUE [WKCOST1]
and:  [Dur1] IS GIVEN THE VALUE [DUR1]
and:  [Name2] IS GIVEN THE VALUE [NAME2]
```

```
and:    [WKcost2] IS GIVEN THE VALUE [WKCOST2]
and:    [Dur2] IS GIVEN THE VALUE [DUR2]
and:    [Name3] IS GIVEN THE VALUE [NAME3]
and:    [WKcost3] IS GIVEN THE VALUE [WKCOST3]
and:    [Dur3] IS GIVEN THE VALUE [DUR3]
and:    [Name4] IS GIVEN THE VALUE [NAME4]
and:    [WKcost4] IS GIVEN THE VALUE [WKCOST4]
and:    [Dur4] IS GIVEN THE VALUE [DUR4]
and:    [Name5] IS GIVEN THE VALUE [NAME5]
and:    [WKcost5] IS GIVEN THE VALUE [WKCOST5]
and:    [Dur5] IS GIVEN THE VALUE [DUR5]
and:    [Name6] IS GIVEN THE VALUE [NAME6]
and:    [WKcost6] IS GIVEN THE VALUE [WKCOST6]
and:    [Dur6] IS GIVEN THE VALUE [DUR6]
and:    [Name7] IS GIVEN THE VALUE [NAME7]
and:    [WKcost7] IS GIVEN THE VALUE [WKCOST7]
and:    [Dur7] IS GIVEN THE VALUE [DUR7]
and:    [Name8] IS GIVEN THE VALUE [NAME8]
and:    [WKcost8] IS GIVEN THE VALUE [WKCOST8]
and:    [Dur8] IS GIVEN THE VALUE [DUR8]
and:    [Tbid1] IS GIVEN THE VALUE [WKCOST1]+[DUR1]*[DRUC]
and:    [Tbid2] IS GIVEN THE VALUE [WKCOST2]+[DUR2]*[DRUC]
and:    [Tbid3] IS GIVEN THE VALUE [WKCOST3]+[DUR3]*[DRUC]
and:    [Tbid4] IS GIVEN THE VALUE [WKCOST4]+[DUR4]*[DRUC]
and:    [Tbid5] IS GIVEN THE VALUE [WKCOST5]+[DUR5]*[DRUC]
and:    [Tbid6] IS GIVEN THE VALUE [WKCOST6]+[DUR6]*[DRUC]
and:    [Tbid7] IS GIVEN THE VALUE [WKCOST7]+[DUR7]*[DRUC]
and:    [Tbid8] IS GIVEN THE VALUE [WKCOST8]+[DUR8]*[DRUC]


/*   RULE NUMBER: 198
RULE: AB-SEVEN-INPUT
IF:
        The number of bidders join the bid is {Seven}
THEN:
        [Name1] IS GIVEN THE VALUE [NAME1]
and:    [WKcost1] IS GIVEN THE VALUE [WKCOST1]
and:    [Dur1] IS GIVEN THE VALUE [DUR1]
and:    [Name2] IS GIVEN THE VALUE [NAME2]
and:    [WKcost2] IS GIVEN THE VALUE [WKCOST2]
and:    [Dur2] IS GIVEN THE VALUE [DUR2]
and:    [Name3] IS GIVEN THE VALUE [NAME3]
and:    [WKcost3] IS GIVEN THE VALUE [WKCOST3]
and:    [Dur3] IS GIVEN THE VALUE [DUR3]
and:    [Name4] IS GIVEN THE VALUE [NAME4]
and:    [WKcost4] IS GIVEN THE VALUE [WKCOST4]
and:    [Dur4] IS GIVEN THE VALUE [DUR4]
and:    [Name5] IS GIVEN THE VALUE [NAME5]
and:    [WKcost5] IS GIVEN THE VALUE [WKCOST5]
and:    [Dur5] IS GIVEN THE VALUE [DUR5]
and:    [Name6] IS GIVEN THE VALUE [NAME6]
and:    [WKcost6] IS GIVEN THE VALUE [WKCOST6]
```

```
and:    [Dur6] IS GIVEN THE VALUE [DUR6]
and:    [Name7] IS GIVEN THE VALUE [NAME7]
and:    [WKcost7] IS GIVEN THE VALUE [WKCOST7]
and:    [Dur7] IS GIVEN THE VALUE [DUR7]
and:    [Tbid1] IS GIVEN THE VALUE [WKCOST1]+[DUR1]*[DRUC]
and:    [Tbid2] IS GIVEN THE VALUE [WKCOST2]+[DUR2]*[DRUC]
and:    [Tbid3] IS GIVEN THE VALUE [WKCOST3]+[DUR3]*[DRUC]
and:    [Tbid4] IS GIVEN THE VALUE [WKCOST4]+[DUR4]*[DRUC]
and:    [Tbid5] IS GIVEN THE VALUE [WKCOST5]+[DUR5]*[DRUC]
and:    [Tbid6] IS GIVEN THE VALUE [WKCOST6]+[DUR6]*[DRUC]
and:    [Tbid7] IS GIVEN THE VALUE [WKCOST7]+[DUR7]*[DRUC]


/*  RULE NUMBER: 199
RULE: AB-SIX-INPUT
IF:
        The number of bidders join the bid is {Six}
THEN:
        [Name1] IS GIVEN THE VALUE [NAME1]
and:    [WKcost1] IS GIVEN THE VALUE [WKCOST1]
and:    [Dur1] IS GIVEN THE VALUE [DUR1]
and:    [Name2] IS GIVEN THE VALUE [NAME2]
and:    [WKcost2] IS GIVEN THE VALUE [WKCOST2]
and:    [Dur2] IS GIVEN THE VALUE [DUR2]
and:    [Name3] IS GIVEN THE VALUE [NAME3]
and:    [WKcost3] IS GIVEN THE VALUE [WKCOST3]
and:    [Dur3] IS GIVEN THE VALUE [DUR3]
and:    [Name4] IS GIVEN THE VALUE [NAME4]
and:    [WKcost4] IS GIVEN THE VALUE [WKCOST4]
and:    [Dur4] IS GIVEN THE VALUE [DUR4]
and:    [Name5] IS GIVEN THE VALUE [NAME5]
and:    [WKcost5] IS GIVEN THE VALUE [WKCOST5]
and:    [Dur5] IS GIVEN THE VALUE [DUR5]
and:    [Name6] IS GIVEN THE VALUE [NAME6]
and:    [WKcost6] IS GIVEN THE VALUE [WKCOST6]
and:    [Dur6] IS GIVEN THE VALUE [DUR6]
and:    [Tbid1] IS GIVEN THE VALUE [WKCOST1]+[DUR1]*[DRUC]
and:    [Tbid2] IS GIVEN THE VALUE [WKCOST2]+[DUR2]*[DRUC]
and:    [Tbid3] IS GIVEN THE VALUE [WKCOST3]+[DUR3]*[DRUC]
and:    [Tbid4] IS GIVEN THE VALUE [WKCOST4]+[DUR4]*[DRUC]
and:    [Tbid5] IS GIVEN THE VALUE [WKCOST5]+[DUR5]*[DRUC]
and:    [Tbid6] IS GIVEN THE VALUE [WKCOST6]+[DUR6]*[DRUC]


/*  RULE NUMBER: 200
RULE: AB-FIVE-INPUT
IF:
        The number of bidders join the bid is {Five}
THEN:
        [Name1] IS GIVEN THE VALUE [NAME1]
and:    [WKcost1] IS GIVEN THE VALUE [WKCOST1]
and:    [Dur1] IS GIVEN THE VALUE [DUR1]
```

```
and:    [Name2] IS GIVEN THE VALUE [NAME2]
and:    [WKcost2] IS GIVEN THE VALUE [WKCOST2]
and:    [Dur2] IS GIVEN THE VALUE [DUR2]
and:    [Name3] IS GIVEN THE VALUE [NAME3]
and:    [WKcost3] IS GIVEN THE VALUE [WKCOST3]
and:    [Dur3] IS GIVEN THE VALUE [DUR3]
and:    [Name4] IS GIVEN THE VALUE [NAME4]
and:    [WKcost4] IS GIVEN THE VALUE [WKCOST4]
and:    [Dur4] IS GIVEN THE VALUE [DUR4]
and:    [Name5] IS GIVEN THE VALUE [NAME5]
and:    [WKcost5] IS GIVEN THE VALUE [WKCOST5]
and:    [Dur5] IS GIVEN THE VALUE [DUR5]
and:    [Tbid1] IS GIVEN THE VALUE [WKCOST1]+[DUR1]*[DRUC]
and:    [Tbid2] IS GIVEN THE VALUE [WKCOST2]+[DUR2]*[DRUC]
and:    [Tbid3] IS GIVEN THE VALUE [WKCOST3]+[DUR3]*[DRUC]
and:    [Tbid4] IS GIVEN THE VALUE [WKCOST4]+[DUR4]*[DRUC]
and:    [Tbid5] IS GIVEN THE VALUE [WKCOST5]+[DUR5]*[DRUC]


/*  RULE NUMBER: 201
RULE: AB-FOUR-INPUT
IF:
        The number of bidders join the bid is {Four}
THEN:
        [Name1] IS GIVEN THE VALUE [NAME1]
and:    [WKcost1] IS GIVEN THE VALUE [WKCOST1]
and:    [Dur1] IS GIVEN THE VALUE [DUR1]
and:    [Name2] IS GIVEN THE VALUE [NAME2]
and:    [WKcost2] IS GIVEN THE VALUE [WKCOST2]
and:    [Dur2] IS GIVEN THE VALUE [DUR2]
and:    [Name3] IS GIVEN THE VALUE [NAME3]
and:    [WKcost3] IS GIVEN THE VALUE [WKCOST3]
and:    [Dur3] IS GIVEN THE VALUE [DUR3]
and:    [Name4] IS GIVEN THE VALUE [NAME4]
and:    [WKcost4] IS GIVEN THE VALUE [WKCOST4]
and:    [Dur4] IS GIVEN THE VALUE [DUR4]
and:    [Tbid1] IS GIVEN THE VALUE [WKCOST1]+[DUR1]*[DRUC]
and:    [Tbid2] IS GIVEN THE VALUE [WKCOST2]+[DUR2]*[DRUC]
and:    [Tbid3] IS GIVEN THE VALUE [WKCOST3]+[DUR3]*[DRUC]
and:    [Tbid4] IS GIVEN THE VALUE [WKCOST4]+[DUR4]*[DRUC]


/*  RULE NUMBER: 202
RULE: AB-THREE-INPUT
IF:
        The number of bidders join the bid is {Three}
THEN:
        [Name1] IS GIVEN THE VALUE [NAME1]
and:    [WKcost1] IS GIVEN THE VALUE [WKCOST1]
and:    [Dur1] IS GIVEN THE VALUE [DUR1]
and:    [Name2] IS GIVEN THE VALUE [NAME2]
and:    [WKcost2] IS GIVEN THE VALUE [WKCOST2]
```

```
and:    [Dur2] IS GIVEN THE VALUE [DUR2]
and:    [Name3] IS GIVEN THE VALUE [NAME3]
and:    [WKcost3] IS GIVEN THE VALUE [WKCOST3]
and:    [Dur3] IS GIVEN THE VALUE [DUR3]
and:    [Tbid1] IS GIVEN THE VALUE [WKCOST1]+[DUR1]*[DRUC]
and:    [Tbid2] IS GIVEN THE VALUE [WKCOST2]+[DUR2]*[DRUC]
and:    [Tbid3] IS GIVEN THE VALUE [WKCOST3]+[DUR3]*[DRUC]


/*  RULE NUMBER: 203
RULE: AB-TEN-BID1
IF:
        The number of bidders join the bid is {Ten}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9],[TBID10])=[TBID1]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR1]
and:    [Fbidname] IS GIVEN THE VALUE [NAME1]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST1]


/*  RULE NUMBER: 204
RULE: AB-TEN-BID2
IF:
        The number of bidders join the bid is {Ten}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9],[TBID10])=[TBID2]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR2]
and:    [Fbidname] IS GIVEN THE VALUE [NAME2]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST2]


/*  RULE NUMBER: 205
RULE: AB-TEN-BID3
IF:
        The number of bidders join the bid is {Ten}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9],[TBID10])=[TBID3]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR3]
and:    [Fbidname] IS GIVEN THE VALUE [NAME3]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST3]


/*  RULE NUMBER: 206
RULE: AB-TEN-BID4
IF:
        The number of bidders join the bid is {Ten}
```

```
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9],[TBID10])=[TBID4]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR4]
and:    [Fbidname] IS GIVEN THE VALUE [NAME4]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST4]


/*  RULE NUMBER: 207
RULE: AB-TEN-BID5
IF:
        The number of bidders join the bid is {Ten}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9],[TBID10])=[TBID5]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR5]
and:    [Fbidname] IS GIVEN THE VALUE [NAME5]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST5]


/*  RULE NUMBER: 208
RULE: AB-TEN-BID6
IF:
        The number of bidders join the bid is {Ten}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9],[TBID10])=[TBID6]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR6]
and:    [Fbidname] IS GIVEN THE VALUE [NAME6]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST6]


/*  RULE NUMBER: 209
RULE: AB-TEN-BID7
IF:
        The number of bidders join the bid is {Ten}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9],[TBID10])=[TBID7]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR7]
and:    [Fbidname] IS GIVEN THE VALUE [NAME7]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST7]


/*  RULE NUMBER: 210
RULE: AB-TEN-BID8
IF:
        The number of bidders join the bid is {Ten}
```

```
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9],[TBID10])=[TBID8]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR8]
and:    [Fbidname] IS GIVEN THE VALUE [NAME8]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST8]


/*   RULE NUMBER: 211
RULE: AB-TEN-BID9
IF:
        The number of bidders join the bid is {Ten}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9],[TBID10])=[TBID9]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR9]
and:    [Fbidname] IS GIVEN THE VALUE [NAME9]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST9]


/*   RULE NUMBER: 212
RULE: AB-TEN-BID10
IF:
        The number of bidders join the bid is {Ten}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9],[TBID10])=[TBID10]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR10]
and:    [Fbidname] IS GIVEN THE VALUE [NAME10]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST10]


/*   RULE NUMBER: 213
RULE: AB-NINE-BID1
IF:
        The number of bidders join the bid is {Nine}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9])=[TBID1]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR1]
and:    [Fbidname] IS GIVEN THE VALUE [NAME1]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST1]


/*   RULE NUMBER: 214
RULE: AB-NINE-BID2
IF:
        The number of bidders join the bid is {Nine}
```

```
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9])=[TBID2]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR2]
and:    [Fbidname] IS GIVEN THE VALUE [NAME2]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST2]


/*   RULE NUMBER: 215
RULE: AB-NINE-BID3
IF:
        The number of bidders join the bid is {Nine}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9])=[TBID3]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day - Confidence=[DUR3]
and:    [Fbidname] IS GIVEN THE VALUE [NAME3]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST3]


/*   RULE NUMBER: 216
RULE: AB-NINE-BID4
IF:
        The number of bidders join the bid is {Nine}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9])=[TBID4]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR4]
and:    [Fbidname] IS GIVEN THE VALUE [NAME4]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST4]


/*   RULE NUMBER: 217
RULE: AB-NINE-BID5
IF:
        The number of bidders join the bid is {Nine}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9])=[TBID5]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR5]
and:    [Fbidname] IS GIVEN THE VALUE [NAME5]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST5]


/*   RULE NUMBER: 218
RULE: AB-NINE-BID6
IF:
        The number of bidders join the bid is {Nine}
```

```
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9])=[TBID6]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR6]
and:    [Fbidname] IS GIVEN THE VALUE [NAME6]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST6]


/*  RULE NUMBER: 219
RULE: AB-NINE-BID7
IF:
        The number of bidders join the bid is {Nine}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9])=[TBID7]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR7]
and:    [Fbidname] IS GIVEN THE VALUE [NAME7]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST7]


/*  RULE NUMBER: 220
RULE: AB-NINE-BID8
IF:
        The number of bidders join the bid is {Nine}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9])=[TBID8]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR8]
and:    [Fbidname] IS GIVEN THE VALUE [NAME8]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST8]


/*  RULE NUMBER: 221
RULE: AB-NINE-BID9
IF:
        The number of bidders join the bid is {Nine}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8],[TBID9])=[TBID9]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR9]
and:    [Fbidname] IS GIVEN THE VALUE [NAME9]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST9]


/*  RULE NUMBER: 222
RULE: AB-EIGHT-BID1
IF:
        The number of bidders join the bid is {Eight}
```

```
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8])=[TBID1]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR1]
and:    [Fbidname] IS GIVEN THE VALUE [NAME1]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST1]


/*  RULE NUMBER: 223
RULE: AB-EIGHT-BID2
IF:
        The number of bidders join the bid is {Eight}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8])=[TBID2]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR2]
and:    [Fbidname] IS GIVEN THE VALUE [NAME2]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST2]


/*  RULE NUMBER: 224
RULE: AB-EIGHT-BID3
IF:
        The number of bidders join the bid is {Eight}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8])=[TBID3]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR3]
and:    [Fbidname] IS GIVEN THE VALUE [NAME3]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST3]


/*  RULE NUMBER: 225
RULE: AB-EIGHT-BID4
IF:
        The number of bidders join the bid is {Eight}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8])=[TBID4]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR4]
and:    [Fbidname] IS GIVEN THE VALUE [NAME4]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST4]


/*  RULE NUMBER: 226
RULE: AB-EIGHT-BID5
IF:
        The number of bidders join the bid is {Eight}
```

```
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8])=[TBID5]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR5]
and:    [Fbidname] IS GIVEN THE VALUE [NAME5]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST5]


/*  RULE NUMBER: 227
RULE: AB-EIGHT-BID6
IF:
        The number of bidders join the bid is {Eight}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8])=[TBID6]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR6]
and:    [Fbidname] IS GIVEN THE VALUE [NAME6]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST6]


/*  RULE NUMBER: 228
RULE: AB-EIGHT-BID7
IF:
        The number of bidders join the bid is {Eight}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8])=[TBID7]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR7]
and:    [Fbidname] IS GIVEN THE VALUE [NAME7]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST7]


/*  RULE NUMBER: 229
RULE: AB-EIGHT-BID8
IF:
        The number of bidders join the bid is {Eight}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7],[TBID8])=[TBID8]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR8]
and:    [Fbidname] IS GIVEN THE VALUE [NAME8]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST8]


/*  RULE NUMBER: 230
RULE: AB-SEVEN-BID1
IF:
        The number of bidders join the bid is {Seven}
```

```
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7])=[TBID1]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR1]
and:    [Fbidname] IS GIVEN THE VALUE [NAME1]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST1]


/*   RULE NUMBER: 231
RULE: AB-SEVEN-BID2
IF:
        The number of bidders join the bid is {Seven}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7])=[TBID2]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day - Confidence=[DUR2]
and:    [Fbidname] IS GIVEN THE VALUE [NAME2]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST2]


/*   RULE NUMBER: 232
RULE: AB-SEVEN-BID3
IF:
        The number of bidders join the bid is {Seven}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7])=[TBID3]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR3]
and:    [Fbidname] IS GIVEN THE VALUE [NAME3]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST3]


/*   RULE NUMBER: 233
RULE: AB-SEVEN-BID4
IF:
        The number of bidders join the bid is {Seven}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7])=[TBID4]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR4]
and:    [Fbidname] IS GIVEN THE VALUE [NAME4]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST4]


/*   RULE NUMBER: 234
RULE: AB-SEVEN-BID5
IF:
        The number of bidders join the bid is {Seven}
```

```
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7])=[TBID5]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR5]
and:    [Fbidname] IS GIVEN THE VALUE [NAME5]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST5]


/*  RULE NUMBER: 235
RULE: AB-SEVEN-BID6
IF:
        The number of bidders join the bid is {Seven}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7])=[TBID6]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR6]
and:    [Fbidname] IS GIVEN THE VALUE [NAME6]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST6]


/*  RULE NUMBER: 236
RULE: AB-SEVEN-BID7
IF:
        The number of bidders join the bid is {Seven}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6],
        [TBID7])=[TBID7]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR7]
and:    [Fbidname] IS GIVEN THE VALUE [NAME7]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST7]


/*  RULE NUMBER: 237
RULE: AB-SIX-BID1
IF:
        The number of bidders join the bid is {Six}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6])
        =[TBID1]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR1]
and:    [Fbidname] IS GIVEN THE VALUE [NAME1]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST1]


/*  RULE NUMBER: 238
RULE: AB-SIX-BID2
IF:
        The number of bidders join the bid is {Six}
```

```
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6])
        =[TBID2]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR2]
and:    [Fbidname] IS GIVEN THE VALUE [NAME2]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST2]


/*   RULE NUMBER: 239
RULE: AB-SIX-BID3
IF:
        The number of bidders join the bid is {Six}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6])
        =[TBID3]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR3]
and:    [Fbidname] IS GIVEN THE VALUE [NAME3]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST3]


/*   RULE NUMBER: 240
RULE: AB-SIX-BID4
IF:
        The number of bidders join the bid is {Six}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6])
        =[TBID4]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR4]
and:    [Fbidname] IS GIVEN THE VALUE [NAME4]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST4]


/*   RULE NUMBER: 241
RULE: AB-SIX-BID5
IF:
        The number of bidders join the bid is {Six}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6])
        =[TBID5]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR5]
and:    [Fbidname] IS GIVEN THE VALUE [NAME5]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST5]


/*   RULE NUMBER: 242
RULE: AB-SIX-BID6
IF:
        The number of bidders join the bid is {Six}
```

```
and:     MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5],[TBID6])
         =[TBID6]
THEN:
         > The contract duration estimated using the "A+B"
         module in working day- Confidence=[DUR6]
and:     [Fbidname] IS GIVEN THE VALUE [NAME6]
and:     [Fbid] IS GIVEN THE VALUE [WKCOST6]


/*   RULE NUMBER: 243
RULE: AB-FIVE-BID1
IF:
         The number of bidders join the bid is {Five}
and:     MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5])=[TBID1]
THEN:
         > The contract duration estimated using the "A+B"
         module in working day- Confidence=[DUR1]
and:     [Fbidname] IS GIVEN THE VALUE [NAME1]
and:     [Fbid] IS GIVEN THE VALUE [WKCOST1]


/*   RULE NUMBER: 244
RULE: AB-FIVE-BID2
IF:
         The number of bidders join the bid is {Five}
and:     MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5])=[TBID2]
THEN:
         > The contract duration estimated using the "A+B"
         module in working day- Confidence=[DUR2]
and:     [Fbidname] IS GIVEN THE VALUE [NAME2]
and:     [Fbid] IS GIVEN THE VALUE [WKCOST2]


/*   RULE NUMBER: 245
RULE: AB-FIVE-BID3
IF:
         The number of bidders join the bid is {Five}
and:     MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5])=[TBID3]
THEN:
         > The contract duration estimated using the "A+B"
         module in working day- Confidence=[DUR3]
and:     [Fbidname] IS GIVEN THE VALUE [NAME3]
and:     [Fbid] IS GIVEN THE VALUE [WKCOST3]


/*   RULE NUMBER: 246
RULE: AB-FIVE-BID4
IF:
         The number of bidders join the bid is {Five}
and:     MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5])=[TBID4]
THEN:
         > The contract duration estimated using the "A+B"
```

```
            module in working day- Confidence=[DUR4]
and:    [Fbidname] IS GIVEN THE VALUE [NAME4]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST4]


/*   RULE NUMBER: 247
RULE: AB-FIVE-BID5
IF:
        The number of bidders join the bid is {Five}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4],[TBID5])=[TBID5]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR5]
and:    [Fbidname] IS GIVEN THE VALUE [NAME5]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST5]


/*   RULE NUMBER: 248
RULE: AB-FOUR-BID1
IF:
        The number of bidders join the bid is {Four}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4])=[TBID1]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR1]
and:    [Fbidname] IS GIVEN THE VALUE [NAME1]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST1]


/*   RULE NUMBER: 249
RULE: AB-FOUR-BID2
IF:
        The number of bidders join the bid is {Four}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4])=[TBID2]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR2]
and:    [Fbidname] IS GIVEN THE VALUE [NAME2]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST2]


/*   RULE NUMBER: 250
RULE: AB-FOUR-BID3
IF:
        The number of bidders join the bid is {Four}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4])=[TBID3]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR3]
and:    [Fbidname] IS GIVEN THE VALUE [NAME3]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST3]
```

```
/*  RULE NUMBER: 251
RULE: AB-FOUR-BID4
IF:
        The number of bidders join the bid is {Four}
and:    MIN([TBID1],[TBID2],[TBID3],[TBID4])=[TBID4]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR4]
and:    [Fbidname] IS GIVEN THE VALUE [NAME4]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST4]


/*  RULE NUMBER: 252
RULE: AB-THREE-BID1
IF:
        The number of bidders join the bid is {Three}
and:    MIN([TBID1],[TBID2],[TBID3])=[TBID1]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR1]
and:    [Fbidname] IS GIVEN THE VALUE [NAME1]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST1]


/*  RULE NUMBER: 253
RULE: AB-THREE-BID2
IF:
        The number of bidders join the bid is {Three}
and:    MIN([TBID1],[TBID2],[TBID3])=[TBID2]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR2]
and:    [Fbidname] IS GIVEN THE VALUE [NAME2]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST2]


/*  RULE NUMBER: 254
RULE: AB-THREE-BID3
IF:
        The number of bidders join the bid is {Three}
and:    MIN([TBID1],[TBID2],[TBID3])=[TBID3]
THEN:
        > The contract duration estimated using the "A+B"
        module in working day- Confidence=[DUR3]
and:    [Fbidname] IS GIVEN THE VALUE [NAME3]
and:    [Fbid] IS GIVEN THE VALUE [WKCOST3]
```

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BIOGRAPHICAL SKETCH

Wei Tong Chen is a native Taiwanese. He attended schools in his home city of Taichung. He then went to the National Taiwan Institute of Technology where he earned his B.S. in engineering. After finishing his undergraduate education, he came to the United States for higher studies and enrolled in the graduate program in the School of Building Construction at the University of Florida. In August 1990 he obtained his master's degree in building construction, and he then entered the Construction Management Program in the Department of Civil Engineering to pursue his doctorate.

Wei Tong was a graduate assistant in the Department of Civil Engineering during his advanced study. He served as a student member of the American Society of Civil Engineers and the American Association of Cost Engineers International. He was also the president of the Chinese Student Association at the University of Florida. He and his wife plan to return to their country after receiving their degrees.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.
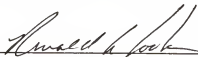
Zohar Herbsman, Chairman
Professor of Civil Engineering

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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This dissertation was submitted to the Graduate Faculty of the College of Engineering and to the Graduate School and was accepted as partial fulfillment of the requirement for the degree of Doctor of Philosophy.

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